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EVALUATION OF **BIOMASS-TO-ETHANOL** FUEL POTENTIAL IN CALIFORNIA

A REPORT TO THE GOVERNOR
AND THE
AGENCY SECRETARY,
CALIFORNIA ENVIRONMENTAL
PROTECTION
as directed by Executive Order D-5-99

Gray Davis, Governor

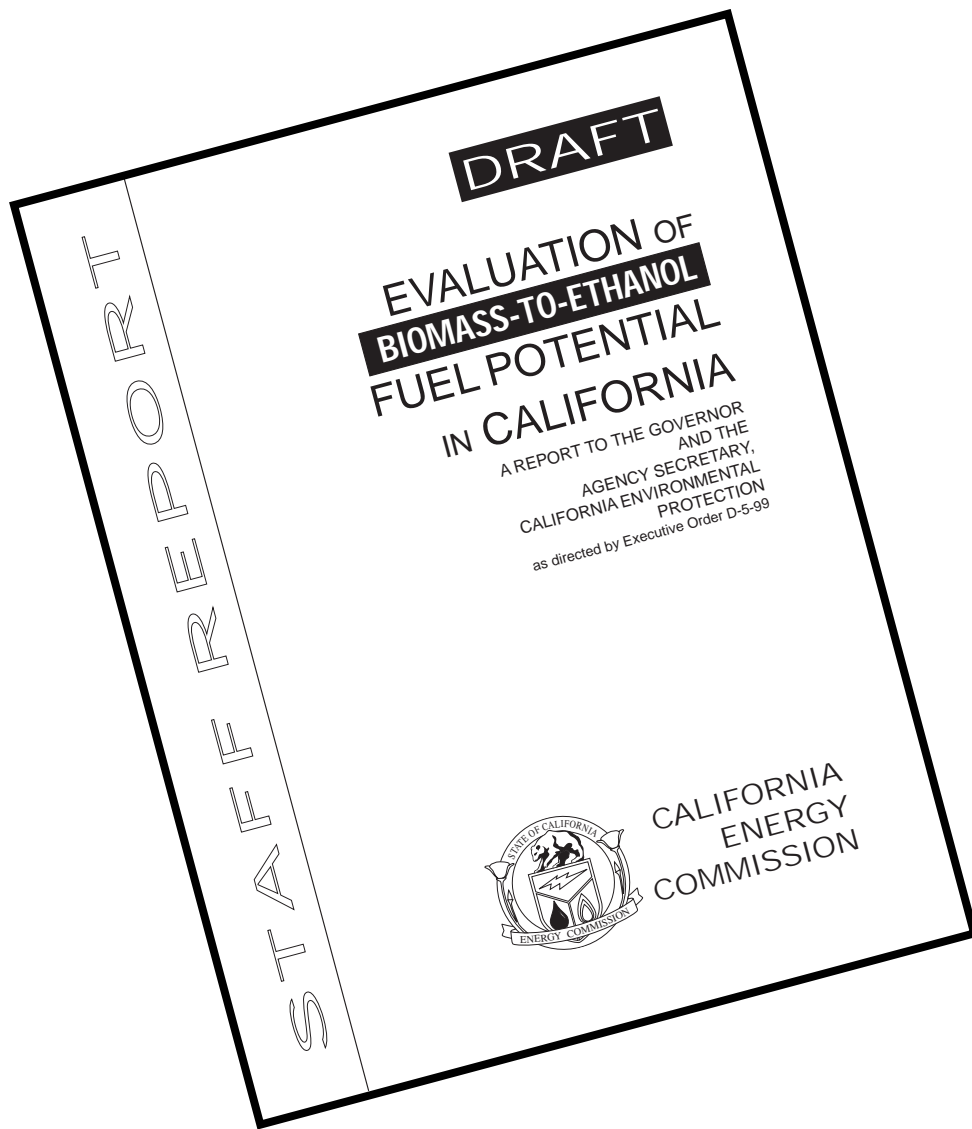
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TECHNICAL APPENDICES

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EXECUTIVE SUMMARY

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Executive Summary

In response to growing evidence that methyl tertiary-butyl ether (MTBE) is contaminating California's groundwater, Governor Gray Davis issued Executive Order D-5-99 calling for the phase out of this gasoline additive. As part of the state's response to the potential environmental and public health risks, the Executive Order directed the California Energy Commission to evaluate California's "potential to develop a waste-based or other biomass ethanol industry." In addition, the Order directed the California Energy Commission to evaluate "what steps, if any, would be appropriate to foster waste-based or other biomass ethanol development in California should ethanol be found to be an acceptable substitute for MTBE."

This draft report presents the major findings, conclusions and preliminary recommendations resulting from the study on the *Evaluation of Biomass-to-Ethanol Fuel Potential in California*. The California Energy Commission staff's analysis shows that ethanol fuel produced from waste, and residual materials offers potential for meeting the state's oxygenated gasoline needs. As a renewable fuel, biomass-to-ethanol fuel production offers a number of potential energy, environmental and economic benefits for California's citizens.

Creating a viable in-state ethanol industry to capture these benefits, however, poses a major challenge. The cost of producing ethanol remains high, requiring continued government price support to make it a competitive fuel additive. Developing a competitive California ethanol industry will also require a state government role to overcome economic, technical and institutional barriers and uncertainties. California-produced ethanol fuel will face stiff competition with out-of-state ethanol supplies and in-state petroleum products.

Commercializing new unproven technologies for converting biomass to ethanol raises uncertainties and presents added challenges that must be overcome to foster and nurture a commercial ethanol industry in California.

The lack of real-world experience with biomass-to-ethanol conversion in California and elsewhere suggests that the State would be prudent to co-fund the first few production facilities as part of a near-term demonstration effort. A demonstration would be particularly valuable to gain insight into the actual benefits and drawbacks to siting, building and operating such facilities in California.

In addition, developing a clear biomass-to-ethanol state policy to guide and coordinate actions can help reduce the many challenges that exist in developing this industry. Supporting activities to encourage the production and use of ethanol fuel as a renewable energy source complements California's ongoing efforts of develop transportation energy alternatives.

The sections below summarize the major findings, conclusions and recommendations of this study.

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Major Findings and Conclusions

Biomass-to-Ethanol Production in the United States and California

Nearly all the ethanol used as fuel in the United States today is produced from corn-based ethanol facilities in the Midwest. Currently, one small biomass-to-ethanol facility in California is operating, using beverage waste, with a capacity of 7.5 million gallons of ethanol a year.

Due to ethanol tax incentives, however, ethanol would probably not be produced and sold in the United States in the motor fuel market today without the federal ethanol excise tax exemption and income tax credits now in place.

MTBE Phase-Out and Demand For Ethanol in California

With the phase-out of MTBE, ethanol use may grow as a gasoline additive to meet federal and state requirements in gasoline. The uncertainty surrounding regulatory decisions will affect the use of ethanol in the future.

If ethanol is used to replace MTBE, the California demand for ethanol may be as high as 1.1 billion gallons a year. Three California projects are in the active planning stages and, if constructed, could produce about 46 million gallons of ethanol a year by 2004. Thus, if used to replace MTBE, most ethanol will initially be supplied from out-of-state sources, primarily corn-based ethanol from the Midwest.

California's Biomass Resources

California generates an estimated 51 million bone dry tons of gross waste biomass resources annually from its large agricultural industry, forests and large volumes of commercial and municipal solid waste materials, that offer potential supply sources for producing ethanol.

The three primary categories of waste and residual biomass resources in California include forest wastes (40%), municipal solid wastes (36%) and agricultural residues (24%).

Ethanol Production Potential from Biomass Resources

The estimated upper limit for ethanol produced from California's waste residues exceeds 3 billion gallons a year. The actual amount that is available, however, is significantly lower once economic, technological and institutional factors are considered.

Many studies of biomass-to-ethanol demonstration projects were previously undertaken in California but did not advance beyond the feasibility phase. In the future, the

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production potential for a California biomass-to-ethanol industry will likely be determined most by the industry's ability to obtain capital and second by its ability to obtain assurances for a reliable long-term supply of low-cost consistent quality feedstock.

Ethanol Production from Biomass Energy Crops

Biomass energy crops, grown for their energy value, represent another approach to supplying feedstocks for ethanol production. While waste-based feedstocks receive greater attention for proposed near-term ethanol production, energy crops represent a potentially larger source of longer-term supplies for ethanol production, but high costs must be overcome.

Currently, there are no plans in evidence to produce ethanol from California-grown energy crops. Limited studies of energy crops, however, have identified sweet sorghum and eucalyptus as possible supply sources in the future.

Government Tax Incentives

The economics of ethanol fuel in the United States are influenced by favorable federal tax provisions, which effectively reduce the retail price of ethanol by 54 cents per gallon. A federal income tax credit is also in place, and a number of Midwest states offer additional state tax incentives.

In California, tax credits are provided to rice farmers who divert rice straw from burning. A diversion credit up to 10 percent for meeting a city or county's 50 percent recycling goal for converting municipal solid waste to ethanol is also available.

Biomass-to-Ethanol Project Economics

Biomass-to-ethanol technologies are still in the demonstration phase. High capital costs associated with the non-commercial status of biomass-to-ethanol technology contribute to high risk financing. Project economics are, therefore, subject to many unknowns and will vary with plant size, location and feedstock costs, which represent the largest portion of the total costs, and many other variables.

Plants collocated with biomass power plants or refuse facilities provide economies that will enhance the potential profitability for biomass-to-ethanol projects. The economics of biomass-to ethanol conversion will also be enhanced when the ethanol production is part of a biomass refinery (biorefinery) that produces ethanol plus electricity, process steam and chemical co-products.

Potential Public Benefits from a Biomass-to-Ethanol Industry

A number of potential public benefits may be derived if a biomass-to-ethanol industry develops in California. Biomass-derived fuels such as ethanol may offer an effective option for reducing greenhouse gases that may contribute to global climate change.

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Studies have shown that greenhouse gas reductions are possible with ethanol produced from biomass compared to non-renewable fuels.

Biomass is also becoming a larger waste disposal issue as agricultural residues, forest and urban wastes grow and the cost for disposing increases. In the past, large quantities of agricultural and forest wastes were burned. Burning of such wastes as rice straw impacts air quality. Open-field burning of rice straw is being phased out and rice straw biomass-to-ethanol facilities could further reduce air pollutants and divert wastes from landfills.

Converting forest biomass to ethanol can help improve forest health and reduce the risk of catastrophic wildfires that cost the state millions of dollars a year. Other benefits that could arise if a biomass-to-ethanol industry develops are the creation of a new industry that could provide new jobs and tax revenue for the state's agricultural, rural and urban economies.

Developing a Biomass-to-Ethanol Policy

The State of California lacks a clear integrated statewide biomass-to-ethanol fuel policy to support ethanol fuel production and use. Such a policy would set the stage for discussion of increased inter-agency coordination, consideration of public-funding strategies, removal of market barriers, and encouragement of new market opportunities. These topics will be discussed at a public workshop at the California Energy Commission on September 10, 1999.

Preliminary Recommendations

Chapter VIII provides a comprehensive list of financial incentives, tax incentives and other public funding strategies for assisting a biomass-to-ethanol industry. Other recommendations to consider include the following:

- The state law which limits the diversion credit for solid waste to ethanol should be amended. Currently, the law allows a maximum of 10% credit when municipal solid waste is diverted to ethanol. Full credit should be allowed for biomass residues diverted from landfills.
- A multidisciplinary/ multi-agency consortium should be established to leverage resources, share information and jointly address issues and challenges facing the biomass-to-ethanol industry

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CHAPTER 1

INTRODUCTION

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I. Introduction

This report responds to Governor Gray Davis' Executive Order D-5-99, item 11, which was issued on March 25, 1999. (Appendix A contains a copy of the complete Executive Order.)

What is the Energy Commission Required to Do?

The Executive Order requires the California Energy Commission to evaluate California's potential to develop a "waste-based or other biomass ethanol industry" and what steps, if any, would be appropriate to "foster waste-based or other biomass ethanol development in California should ethanol be found to be an acceptable substitute for methyl tertiary-butyl ether (MTBE)."

What Are Other Agencies Required to Do?

In addition, the Executive Order requires other state agencies to undertake a series of activities to mitigate the environmental effects of MTBE and examine the environmental and health implications of ethanol use in place of MTBE.

Since the other investigations that bear on the role ethanol might ultimately play in California's gasoline supply picture are ongoing, this evaluation of in-state ethanol supply potential does not assume the outcomes of these other related studies.

Ethanol as California's Response to the MTBE Issue

Ethanol, an alcohol, is a primary candidate for replacing MTBE, with a considerable history of use both as a gasoline additive and a direct motor fuel. The Executive Order (in item 11) directs the California Energy Commission to undertake new investigations of the potential for employing ethanol, and for producing ethanol in California, in response to the phase out of MTBE use.

The California Energy Commission began work on biomass-based ethanol production and its use in transportation nearly two decades ago. Beginning in 1980, several demonstrations were conducted to investigate the practicality and cost effectiveness of alcohol motor fuels. While this early work showed that ethanol production was potentially viable in the state, it became evident that the economics for in-state production were not competitive with corn-derived ethanol from the Midwest.

More recent work at the California Energy Commission has identified a wide variety of biomass resources in California that may be suitable feedstocks for ethanol production.

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How Was This Report Reviewed?

This study has benefited from comments received and input provided by a technical Peer Review Group of experts who reviewed the outline and an earlier working draft version of this report. A list of the technical Peer Review Group members is provided in Appendix J. The technical experts represent a diverse panel of individuals with particular knowledge and involvement in the field of biomass, ethanol and alternative fuels.

A public workshop is scheduled for September 10, 1999 at the California Energy Commission in Sacramento to receive comments and input on the report. Public hearings will follow in November and December to solicit additional input as the report evolves. The final report is due to Governor Gray Davis in late December 1999.

How Is This Report Organized?

This report has been organized for a general audience, with the technical details and documentation for the chapters in Appendices. The following describes the contents of each chapter:

Chapter II, "Ethanol as a Fuel - Background," summarizes the history of ethanol as a motor fuel and the role of federal and state tax incentives in fostering an ethanol market. This chapter also discusses federal and state air quality regulations affecting the use of ethanol, the current status of ethanol production and use, and the role of ethanol in the phase out of MTBE.

Chapter III, "Waste Biomass Resources in California," defines and describes biomass, waste biomass and residues identified as candidates for ethanol production. In addition, estimates of the physical resource potential in California for various wastes and residual biomass categories are discussed. The economic and environmental factors and challenges, including competing markets and alternative disposal options affecting the viability of ethanol production, are also examined. Appendix C contains the technical details and documentation on which this chapter is based.

Chapter IV, "Biomass Crop Resource Potential in California," examines the potential for producing ethanol in California from biomass energy crops. It identifies different types of crops that are candidate feedstocks for ethanol production, reviews previous studies of the potential for energy crop-based ethanol production in the state, and discusses key factors that affect the prospects for achieving this potential.

Chapter V, "Biomass Conversion," describes the most competitive current technologies and probable improvements to increase the rate of conversion, yields and efficiency of production of ethanol, electricity, and co-products from urban, agricultural, and forest wastes. The chapter also surveys the various technologies for converting biomass, research on methods to improve them, and possible

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features of a mature biorefinery industry, including opportunities to lower the costs of ethanol produced. Appendix D contains the technical details and documentation on which this chapter is used.

Chapter VI, “Biomass-to-Ethanol Production Potential in California,” develops estimates of the maximum ethanol production potential in California and what is producible after addressing key technological, economic, and institutional issues. Appendix E and F contain the technical details and documentation on which this chapter is used.

Chapter VII, “Economic Evaluation,” assesses the economics of biomass-to-ethanol production in California compared with obtaining ethanol from conventional sources. The analysis includes a number of different production scenarios, which incorporate different feedstock and process options along with other implications such as employment. Appendix G and H contain the technical details and documentation on which this chapter is used.

Chapter VIII, “Steps to Foster a Biomass-to-Ethanol Industry in California,” presents the major issues that are likely to affect a biomass-to-ethanol industry in California, including issues about feedstock supply and ethanol product as well as ethanol demand. Financial incentives and other forms of support are presented for consideration. Appendix I contains the technical details and documentation on which this chapter is used.

Additionally, the report includes several appendices that provide more information on key topics. Because of the size and number of appendices, they have been printed separately from the main body of the report. They are listed here for reference:

Appendices

Appendix A	Governor Davis’ Executive Order D-5-99
Appendix B	Glossary
Appendix C	Chapter III, Waste Biomass Resources in California
Appendix D	Chapter V, Biomass Conversion Options
Appendix E	Chapter VI, Composition and Yields of Biomass Resources
Appendix F	Chapter VI, Location of Solid Waste Handling Facilities in California
Appendix G	Chapter VII, Feedstock Evaluation Costs and Economic Modeling
Appendix H	Chapter VII, Ethanol Market: Current Production Capacity Future Supply Prospects, and Cost Estimates for Calif.
Appendix I	Chapter VII, State Incentives, Initiatives and Programs
Appendix J	Peer Review Group List
Appendix K	Ethanol Information from the Governors’ Ethanol Coalition

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CHAPTER II

ETHANOL AS A FUEL – BACKGROUND

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II. Ethanol as a Fuel -- Background

Introduction

This chapter summarizes the history of ethanol as a motor fuel, the role of federal and state tax incentives in fostering an ethanol market, federal and state air quality regulations affecting ethanol use, the current status of ethanol production and use, and the role of ethanol in the phase out of MTBE.

What is the History of Ethanol as a Motor Vehicle Fuel?

Since the earliest days of the automobile, alcohols have been used as a fuel; the term alcohol has often been used to denote ethanol or methanol as a fuel. One of the earliest advocates, Henry Ford adapted his Model T to run on either gasoline or alcohol and sponsored alcohol fuel conferences (1).

In 1917, Alexander Graham Bell noted the benefits of alcohol fuel in a commencement address which was published in the National Geographic (2). With gasoline relatively inexpensive, though, alcohols did not achieve a substantial market as a fuel.

In the 1930s, the Depression brought a new interest in farm products, and ethanol and gasoline were blended for the first time. The American Automobile Association conducted the first testing program in 1933. During the 1930s, ethanol fuel gained market share in other countries such as Germany, Brazil, New Zealand and France.

With the oil crises of the 1970s, ethanol became more established as an alternative fuel. Various countries, including Brazil and the United States, undertook national programs to promote domestically-produced ethanol. In addition to the energy rationale, ethanol/gasoline blends in the United States were promoted as an environmentally-driven practice, first as an octane enhancer to replace lead and then more recently as an oxygenate in clean-burning gasoline to reduce vehicle exhaust emissions.

Brazil has promoted ethanol from sugar cane as an alternative fuel, used both in ethanol/gasoline blends and in dedicated ethanol vehicles. As of 1996, after over twenty years of varying degrees of government support for ethanol, Brazil uses about 3.5 million gallons of ethanol annually to supply about 40 percent of its automotive fuel use (3, 4). Other countries currently producing and using ethanol fuel include France, Korea, Mexico, Australia, Canada and Sweden.

In the United States, ethanol supplies represent one percent of the highway motor vehicle fuel market—in the form of ethanol/gasoline blends. Currently, almost all of the ethanol is a 10 percent blend with gasoline traditionally referred to a “gasohol,” a term which is being replaced with “ethanol/gasoline blends” or “E10.”

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Have Federal and State Tax Incentives Fostered an Ethanol Market?

Tax incentives have played a critical role in fostering an ethanol market in the United States. This issue has been and will continue to be debated at the federal and state level.

Federal Tax Incentives

In 1978, Congress enacted the first tax incentive for ethanol, an excise tax exemption. Originally, this incentive was a full exemption from the 4 cents per gallon gasoline tax which was then in place. Currently, two separate federal tax incentives apply to biomass-derived ethanol sold as fuel: 1) an excise tax exemption and 2) an income tax credit for businesses producing or selling ethanol (5).

As the federal gasoline excise tax has increased, the excise tax exemption on ethanol has increased from the original 4 cents to 5.4 cents per gallon. The key point is that the full exemption, 5.4 cents per gallon, applies to ethanol/gasoline blends which are 10 percent ethanol. Proportionately lower amounts apply to lower ethanol/gasoline blends, 7.7 percent and 5.7 percent blends. In effect, this exemption structure provides a 54 cents per gallon exemption from excise taxes for each gallon of ethanol that is blended with gasoline.

In place of the excise tax exemption discussed above, certain businesses can take one of the following income tax credits:

- (1) A 54 cents per gallon credit for each gallon of blended ethanol.
- (2) The same 54 cents per gallon credit for the sale or use of neat alcohol (neat alcohol is defined as fuel with 85 percent or more alcohol).
- (3) A small ethanol producers credit, which allows businesses that produce less than 15 million gallons of ethanol per year a 10 cents per gallon credit for each gallon of ethanol produced.

In 1998, Congress voted to extend the incentive until December 31, 2007. The effective amounts of the incentives, however, are to be reduced from the current 54 cents per gallon level to 53 cents in 2001 and 2002, 52 cents in 2004, and 51 cents in 2005 through 2007. This issue is likely to be debated before the 2007 sunset date. Table II-1 traces the history of the federal ethanol tax incentives.

These federal tax incentives allow ethanol fuel to be sold in the marketplace for 54 cents per gallon less than if these incentives were not in place. By most estimates, this figure amounts to roughly one-half the actual wholesale cost to produce ethanol, allowing ethanol to enter the fuel market at a cost closer to, but still higher than, that of gasoline on an energy equivalent basis.

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Table II-1: Federal Tax Exemption for Ethanol/Gasoline Blends									
	before 1978	1978-82	1982-84	1984-90	1990-93*	1993-2000	2001-02	2003-04	2005-07
Federal Gasoline Excise Tax (cents/gal.)	4	4	9	9	14	18.3	?	?	?
Excise Tax Exemption for 10% Ethanol Blends (cents/gal.)	--	4	5	6	5.4	5.4	5.3	5.2	5.1
Blender's Income Tax Credit for Ethanol (cents/gal.)	--	--	40 (as of 1980)	60	54	54	53	52	51
<small>* Small producer's credit added in 1990 (10 cents/gal. for first 15 million gals. for qualified small producers with annual output less than 30 million gals. Excise tax exemption became applicable to 7.7% blends (currently 4.158 cents/gal.) and 5.7% blends (currently 3.078 cents/gal.) as of 1992</small>									

State Tax Incentives

At least 30 states, including California, have adopted their own ethanol tax incentives at one time or another, with most patterned after and adding to the federal incentives.

From 1981 to 1984, California had a state ethanol incentive in the form of a 3 cents per gallon exemption for 10 percent ethanol/gasoline blends from state gasoline excise tax, which was then 7 cents per gallon. This excise tax amounted to a 30 cents per gallon incentive for ethanol blended this way. Since the sunset of California's incentive, ethanol/gasoline blends are assessed the full state gasoline excise tax, now 18 cents per gallon.

Neat alcohol fuels are taxed at one-half the prevailing gasoline rate. For ethanol in the form of E85, this rate represents about 70 percent of the gasoline excise tax rate on an energy equivalent basis.

How do Federal and State Air Quality Regulations Affect Markets for Ethanol Fuel?

Currently, several federal and state laws govern how ethanol may be blended in gasoline in California.

Federal Regulations

The federal Clean Air Act and its several amendments empower the United States Environmental Protection Agency (EPA) to control properties of gasoline, including the oxygen content and fuel vapor pressure. Ethanol and MTBE have been used by the oil industry to meet oxygen content requirements established in the Clean Air Act Amendments of 1990.

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Specifically with regard to ethanol, a waiver granted by EPA under Section 211(f) of the Act in 1978 allowed ethanol to be blended with gasoline at 10 percent by volume and sold commercially. Under the waiver, the resultant “splash blend” of gasoline and ethanol can have a higher volatility (vapor pressure) than gasoline alone. To control evaporative emissions from vehicles and fueling facilities, EPA placed limits on the volatility of gasoline in 1989 and again in 1992 in ozone non-attainment areas in the southern states. However, ethanol/gasoline blends were exempted from the 7.8 psi Reid Vapor Pressure (RVP) limit.

In 1990, EPA adopted a wintertime oxygen content rule to combat carbon monoxide (CO) in areas not in attainment with the National Ambient Air Quality Standard for CO. These regulations apply today to all states (excluding California) and require a minimum of 2.7 weight percent oxygen for the wintertime months.

In 1995, federal reformulated gasoline (RFG) regulations were implemented for the nine extreme or severe ozone non-attainment regions across the country. Three of these regions are in California. California reformulated gasoline regulations adopted in 1992 and again in 1996 took precedence over federal RFG. Both these regulations contain fuel volatility controls and oxygen requirements.

California Regulations

California has adopted several regulations to control ozone-forming emissions from gasoline vehicles and gasoline and fueling facilities over the years. While these regulations have generally restricted the practice of “splash blending” of ethanol in finished California gasolines since 1990, a volatility exemption provided for significant use of ethanol in blends with gasoline in the 1980s.

Phase 1 Reformulated Gasoline. This reformulated gasoline was implemented statewide in 1992. The regulation reduced the summertime gasoline volatility to 7.8 pound per square inch (psi) RVP. Unlike the federal requirement implemented in 1992, the 7.8 psi limit was instituted statewide, not just in ozone non-attainment regions. The regulation did not allow an exemption from this requirement for 10 percent ethanol/90 percent gasoline blends.

Winter Oxygen Requirement. In response to the federal wintertime oxygen requirement under the Clean Air Act Amendments of 1990, California implemented its program in the winter of 1992. California was allowed to set its own limit on oxygen at 2.0 weight percent based on evidence that NO_x emissions increase at higher oxygen content in California vehicles. Ethanol was used in wintertime gasoline in northern California CO non-attainment regions that year, however, MTBE has become the preferred wintertime oxygenate.

Phase II Reformulated Gasoline. California’s current reformulated gasoline (also referred to as California Cleaner Burning Gasoline- CBG) was implemented statewide in 1996. This regulation places limits on eight gasoline parameters and composition and is

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often referred to as a “recipe”. It also further reduces the allowable RVP to 6.8 psi statewide and institutes an oxygen requirement of 2.0 weight percent year around. Ethanol can be blended into CBG to meet the oxygen requirement and refiners are currently doing so on a small scale (2.0 weight percent oxygen corresponds to 5.7 volume percent ethanol in the gasoline).

This regulation also allows refiners to choose between the “recipe” and a mathematical model, called the “predictive model”. This model gives greater flexibility to the refiners in formulating complying blends of CBG by allowing them to trade off some gasoline parameters for others provided that vehicle emissions (calculated by the model) do not exceed those of the recipe. Under the original predictive model, 2.7 weight percent oxygen is allowed, corresponding to 7.7 volume percent ethanol, however, the RVP must remain at 6.8 psi maximum. In 1998, the oxygen limit was further increased to 3.5 weight percent when using the predictive model based on new data. At this level, ethanol can be blended at 10 volume percent, however, RVP must still be maintained at 6.8 psi.

Although California refiners have chosen MTBE as the oxygenate of choice to meet CBG requirements, ethanol is the most likely replacement given the Governor’s phase out of MTBE. Some current blending of ethanol in premium gasoline in the San Francisco Bay Area confirms the ability of refiners to use the predictive model to blend compliant CBG using ethanol.

Phase III Reformulated Gasoline. The California Air Resources Board is currently developing California Phase III gasoline regulations. The oxygen requirement could be reduced or eliminated based on data from the Auto/Oil Air Quality Improvement Research Program (6) and ARB’s own data. These programs provided evidence that non-oxygenated gasoline conforming to CBG specifications (excepting oxygen) could yield vehicle emissions equivalent to fully complying CBG (containing MTBE). A large vehicle test program in progress will generate new data for an updated predictive model later this year (7). Variable oxygen content is one of the test parameters along with others.

Under the Governor’s executive order, ARB has requested that the federal government rescind the oxygen requirement of the Clean Air Act Amendment of 1990. Even with a zero oxygen requirement, California refiners need to blend ethanol to make up for lost volume and octane when MTBE is phased out of gasoline. Under a longer term scenario modeled for California refiners by an industry consultant, a least cost (to refiners) average oxygen requirement over the course of one year yields a 1 weight percent oxygen requirement. This would amount to about 3.8 volume percent ethanol, on average, in the Phase III gasoline pool for the modeled year 2006 (8).

Fuel Volatility Restrictions. In 1991, the California Legislature and Governor passed legislation that exempted 10 percent ethanol/90 percent gasoline blends from the California gasoline volatility restrictions. This legislation contained a clause which would make this blended fuel legal only if ARB determined through testing of a representative group of vehicles using this fuel that emissions did not increase relative to

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fully complying CBG (with MTBE). In 1998, the California Air Resources Board formally made that determination, that such a blend of ethanol and gasoline increased the ozone-forming potential of the combination of evaporative and exhaust emissions. As a result, all ethanol/gasoline blends must comply with the oxygen and Reid Vapor Pressure requirements of the regulations.

Air Quality Benefit Study. The National Research Council recently released a report on the ozone-forming potential of reformulated gasoline (9). This study looked in detail at the role of oxygenates in improving the performance of reformulated gasoline to reduce ozone. The Committee concluded, *“The use of commonly available oxygenates in RFG has little impact on improving ozone air quality and has some disadvantages”*. The report cited evidence of increases in NO_x emissions with oxygenates in general, but allowed that there were advantages regarding reductions in toxic emissions. The Committee also concluded, *“...it appears likely that the use of ethanol containing RFG with an RVP that is 1 psi higher than other RFG blends would be detrimental to air quality in terms of ozone.”*

Ethanol in Flexible Fuel Vehicles

In 1993, California established specifications for E-85, a mixture of 85 percent ethanol and 15 percent gasoline for vehicles designed specifically for this fuel. Although not currently available in California, E-85 could emerge as a fuel for the future if the economics become favorable either through reduced costs or through active marketing. Currently, flexible fuel vehicles, designed for E-85, are being increasingly sold in California. All of the United States “Big Three” auto manufacturers currently market flexible fuel vehicles such as pickup trucks or vans, resulting in a growing population of “ethanol capable” vehicles.

Global Climate Change and the Role of Waste Biomass-to-Ethanol

The transportation sector is the largest single contributor of carbon dioxide emissions among all energy sectors in California and thus the single most significant emission source contributing to the complex phenomena of global climate change. The most recent emission inventory of carbon dioxide emissions in California shows that nearly 57 percent of the CO₂ was generated by transportation (1). Electricity generation is the next largest at 16 percent contributing roughly one quarter of what the transportation sector generates.

In comparison to the rest of the United States, California has the highest fraction of transportation CO₂ emissions compared to other states and regions of the country. If California is ultimately required under a new federal law to roll back CO₂ emissions, then the focus of any effort must be on its transportation sector.

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Ethanol derived from cellulose has been specifically identified as one potential strategy among others to help reach carbon reduction goals under discussion in the United States (2). Based on analysis by Argonne National Laboratory, ethanol in the form of E-85 derived from cellulosic biomass can reduce carbon emissions in the range of 80 to 85%. In its pure form, ethanol (E100) can achieve reductions of 100 percent based on a full fuel cycle analysis relative to reformulated gasoline (3). This calculation assumes process energy to derive the ethanol is provided primarily by renewable resources. When blended with gasoline at 2.7 weight percent oxygen (7.7 volume percent ethanol), a resultant oxygenated reformulated gasoline achieves about an 8 percent reduction in greenhouse gases relative to reformulated gasoline.

This same analysis also shows that corn-based ethanol can reduce carbon emissions because it likewise is a renewable resource. However, because of fossil fuel inputs required for process energy, current corn derived ethanol achieves about a 22 percent reduction in carbon in the form of E85 fuel. As E100, the carbon reduction is about 32 percent relative to the full fuel cycle emissions associated with reformulated gasoline. In addition, the analysis shows that methanol from cellulosic biomass can achieve carbon reductions up to 100 percent as well.

- (1) “1997 Global Climate Change – Greenhouse Gas Emissions Reduction Strategies for California Volume 2”, California Energy Commission, pub. # P500-98-00IV2, January 1998.
- (2) DeCicco, J. and Mark, J., “Meeting the energy and climate challenge for transportation in the United States”, Energy Policy, Vol.26, No.5, pp. 395-412, 1998.
- (3) Wang, M.Q., “GREET 1.0 – Transportation Fuel Cycles Model: Methodology and Use”, ANL/ESD-33, Argonne National Laboratory, 1996 (updated 1997).

What is the Production Status of Ethanol as a Motor Vehicle Fuel?

As shown in Figure II-1, 1998 U.S. ethanol production tied the previous (1995) record level of 1.4 billion gallons. 1999 production is expected to set a new record (10). Most of the states with ethanol production plants have some incentive for ethanol production or use. Illinois and Minnesota lead the nation in sales of ethanol blends, with each using well over 100 million gallons annually (11).

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U.S. Fuel Ethanol Production

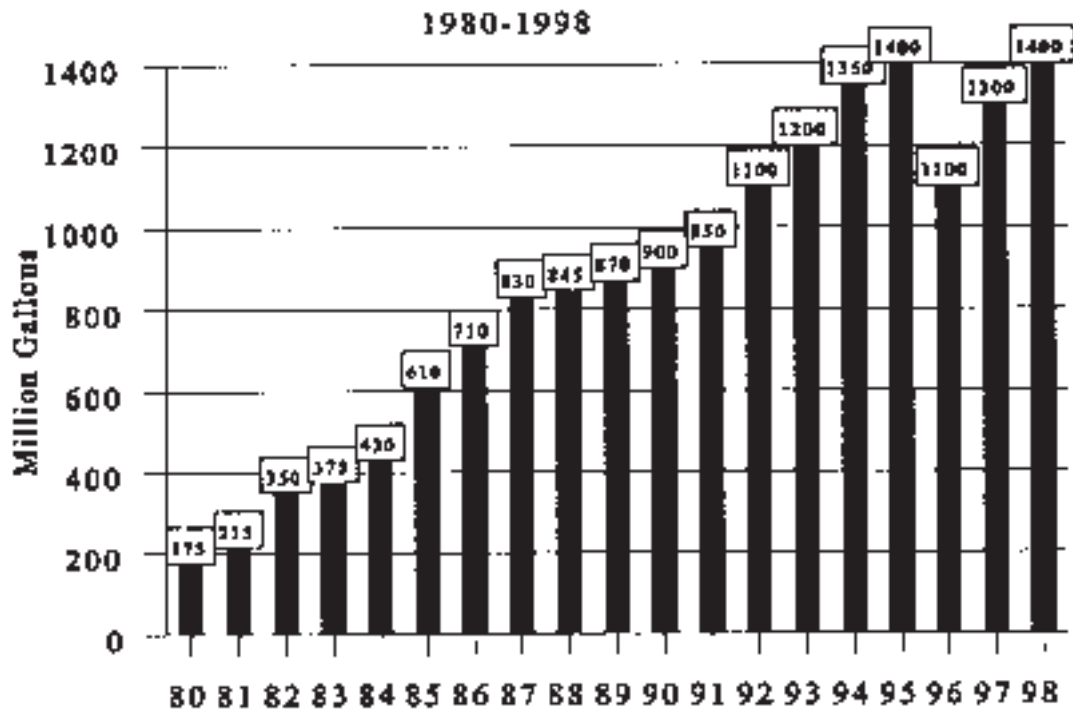


Figure II-1

Source: Governor's Ethanol Coalition

Ethanol Production in the Corn Belt States

Nearly all of the ethanol now being used as fuel in the United States is produced from corn feedstock in plants located in the Midwest corn belt states (see Table II-2). Approximately 6 percent of the country's corn crop is presently used to make ethanol (12). About a dozen plants, with individual capacities of 30 to over 300 million gallons per year, make up 75 percent of the total ethanol industry capacity of about 1.7 billion gallons per year. These plants are located in Illinois, Iowa, Minnesota, Nebraska, Indiana, Ohio, Tennessee and North Dakota.

Archer Daniels Midland, the largest United States ethanol producer, once supplied over half of the country's ethanol. As of 1997, however, Archer Daniels Midland's share was down to about 34 percent, with more medium and small-size producers entering the market (13).

Ethanol Production in Other States

Ethanol production is beginning in states beyond the corn belt, as at least 19 states are now reporting some ethanol production. Although corn remains the feedstock for most production, applications of other crops and waste-based feedstocks are increasing. For example, potatoes are the feedstock in Idaho, ethanol, wheat gluten and cheese whey are

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used in Minnesota, brewery waste and wood are used in Colorado and Washington, grain sorghum in Nebraska and New Mexico, and various agricultural residues and paper in Wisconsin.

New U.S. Production Capacity

Also shown in Table II-2 are new ethanol production plants either under construction or proposed to be built in the U.S. The six projects under construction will add 97 million gallons per year of new capacity. The 17 proposed projects represent 432 million gallons per year of new capacity. Three of the proposed projects are in California, and are discussed further in a subsequent section.

Ethanol Imports

Once significant, ethanol imports to the United States have become negligible in recent years, due to imposition of a high import tariff on most foreign sources. Brazilian ethanol, the largest potential foreign supply source – and a past supplier of significant quantities of ethanol to California and other U.S. markets – is effectively constrained from being imported to the U.S. under the prevailing tariff provisions.

What is California's Experience with Ethanol Production?

California's experience with ethanol fuel production has included a number of project feasibility studies, demonstration projects and several small commercial ventures.

Today, one ethanol production facility is operating in the state, a 7.5 million-gallon per year (gpy) capacity commercial plant operated by Parallel Products at Rancho Cucamonga in Los Angeles County. This plant, occupying a former winery, uses biomass from wine making and other food and beverage industries as its feedstocks. Two other small commercial ethanol plants operated by Golden Cheese Company of California (Corona) and Dairyman's Cooperative Creamery (Tulare), have produced ethanol using cheese whey as feedstock. These plants have a total capacity of about 3.3 gpy; however, they are not currently in operation.

Both the California Energy Commission and the California Department of Food and Agriculture have sponsored studies and demonstrations of ethanol production in California. The California Integrated Waste Management Board has also looked at ethanol production as part of its overall investigations of beneficial applications of various waste materials in the state.

As required by Senate Bill 620 of 1979, the Energy Commission carried out an investigation of alcohol fuels that included both ethanol fuel production feasibility studies and demonstrations and vehicle fleet demonstrations (14,15). Seven potential ethanol

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TABLE II-2 U.S. ETHANOL PRODUCTION CAPACITY (CONT.)

Current Production Capacity

Current Production Capacity				
COMPANY	LOCATION		FEEDSTOCK	MMPY
A.E. Staley	Loudon	TN	Corn	45
AGP*	Hastings	NE	Corn	45
Agri-Energy*	Luverne	MN	Corn	15
Alchem	Grafton	ND	Corn	10.5
Al-Corn*	Claremont	MN	Corn	15
Archer Daniels Midland (total capacity)	Decatur	IL	Corn	750
	Peoria	IL	Corn	
	Cedar Rapids	IA	Corn	
	Clinton	IA	Corn	
	Walhalla	ND	Corn/barley	
Broin Enterprises	Scotland	SD	Corn	7
Cargill (total capacity)	Blair	NE	Corn	100
	Eddyville	IA	Corn	
Central Minnesota*	Little Falls	MN	Corn	15
Chief Ethanol	Hastings	NE	Corn	40
Chippewa Valley Ethanol*	Benson	MN	Corn	17
Corn Plus	Winnebago	MN	Corn	17.5
Eco Products of Plover	Plover	WI	Whey/potato waste	4
ESE Alcohol	Leoti	KS	Corn/milo	1.1
Ethanol2000*	Bingham Lake	MN	Corn	15
Exol, Inc.*	Albert Lea	MN	Corn	15
Georgia-Pacific	Bellingham	WA	Paper waste	7
Golden Cheese*	Corona	CA	Whey	2.8
Grain Processing Corp.	Muscatine	IA	Corn	10
Heartland Corn Products*	Winthrop	MN	Corn	10
Heartland Grain Fuel*	Aberdeen	SE	Corn	8
High Plains Corporation (total capacity)	York	NE	Corn/milo	68
	Colwich	KS		
	Portales	NM		
J.R. Simplot	Caldwell	ID	Potato waste	3
	Burley	ID	Potato waste	3
Jonton Alcohol	Edinburg	TX	Corn	1.2
Kraft, Inc.	Melrose	MN	Whey	3
Manildra Ethanol	Hamburg	IA	Corn/milo/wheat/star ch	7
Merrick/Coors	Golden	CO	Brewery waste	1.5
Midwest Grain (total capacity)	Pekin	IL	Corn/wheat starch	108
	Atchison	KS		
Minnesota Clean Fuels (MN report says .5)	Dundas	MN	Waste sucrose	1.5
Minnesota Corn Processors *(total capacity)	Columbus	NE	Corn	110
	Marshall	MN	Corn	
Minnesota Energy*	Buffalo Lake	MN	Corn	12
Morris Ag Energy	Morris	MN	Corn	8
Nebraska Energy (Williams Energy)	Aurora	NE	Corn	
New Energy Corp.	South Bend	IN	Corn	85
Pabst Brewing	Olympia	WA	Brewery waste	0.7
Parallel Products	Louisville	KS	Beverage waste	7
	Bartow	FL	Beverage waste	5
	R. Cucamonga	CA	Beverage waste	3
Pro-Corn*	Preston	MN	Corn	15
Reeve Argri-Energy	Garden City	KS	Corn/milo	10
Williams Energy Services	Pekin	IL	Corn	130
Wyoming Ethanol	Torrington	WY	Corn	5
Subtotal Current Production Capacity				1,737

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Table II-2 U.S. Ethanol Production Capacity (cont.)

Plants Under Construction				
COMPANY	LOCATION		FEEDSTOCK	MMPY
Adkins Energy*	Lena	IL	Corn	30
BC International	Jennings	LA	Bagasses/rice hulls	20
Nebraska Nutrients	Sutherland	NE	Corn	15
NE Missouri Grain Processors*	Macon	MO	Corn	15
Heartland Corn Products*	Huron	SD	Corn	12
Sunrise Energy*	Blairstown	IA	Corn	5
Subtotal Under Construction Capacity (by 2000)				97

Proposed Plants				
COMPANY	LOCATION		FEEDSTOCK	MMPY
Golden Triangle*	St. Joseph	MO	Corn	25
American Agri-Technology Corporation	Great Falls	MT	Wheat/Barley	30
Lower Caskaskia Economic Devp. Board	Lower Caskaskia	IL	Corn	100
Quincy Library Group	NE Region	CA	Forest Residues	15
BC International (Sacramento Valley)	Gridley	CA	Rice Straw	30
Arkenol*	Mission Viejo	CA	Rice Straw	8
MASADA	Middletown	NY	Municipal Solid Waste	6.6
Sustainable Energy Devp.	Central Region	OR	Wood Waste	30
Pacific Rim Ethanol Corp.	Moses Lake	WA	Grain	40
Pacific Rim Ethanol Corp.	Longview	WA	Grain	40
Shmidt Brewery	St. Paul	MN	Beer waste	5
Green Leaf	Platte	SD	Corn	15
Pratte Project	Pratte	KS	Corn/milo	15
Iowa #1	Central Iowa	IA	Corn	15
Iowa #2	Central Iowa	IA	Corn	15
SIRS	Central Missouri	MO	Corn	30
N/a	Black Hills	SD	Forest Residues	12
Subtotal Proposed Capacity (by 2000)				431.6

TOTAL CURRENT AND PROJECTED ETHANOL PRODUCTION CAPACITY				2,266
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MMPY = million gallons per year

* Cooperatives

Source: Bryan & Bryan Ince. (provided by the Governors' Ehtanol Coalition)

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production projects were examined as part of this program. Table II-3 summarizes the projects that were studied.

Most of these prospective projects were judged not viable, based on various economic, technical and environmental factors. The estimated ethanol production costs for the first six potential projects listed in Table II-3 ranged from \$1.82 to \$2.36 (in 1982) per gallon. Even with the federal and state fuel tax incentives then in place, this range of production costs was considered prohibitively expensive, and none of these projects were pursued beyond the feasibility phase.

Table II-3: Energy Commission Ethanol Production Feasibility Studies				
Project Name	Location	Capacity	Feedstock(s)	Cogeneration
Tulare Ethanol Production Company	Tulare County	3 Million GPY	Corn, almond hulls, cull fruit	Biomass-fired boiler for process heat
City of Tulare	Tulare County	25,000 GPY	Corn	Biomass-fired boiler for process heat
Adams Alcohol Company	Yolo County	10 Million GPY	Grains	Biomass-fired boiler for process heat & electricity
Golden By-Products	Stanislaus County	2.6 million GPY	Almond hulls	Biomass-fired boiler for process heat
Still Gas, Inc.	San Joaquin County	4.5 million GPY	Corn or sweet sorghum	Biomass-fired boiler for process heat
Joe Garone Farms	Kern County	10 million GPY	Grains & agricultural wastes	Biomass-fired boiler for process heat & electricity
Raven Distillery	Fresno County	8 million GPY	Cull fruit	Natural gas for process heat

The Raven Distillery, the one project selected by the Energy Commission to undertake a demonstration, became the first facility in California to actually produce and market fuel ethanol. This project was located at a pre-existing winery in the town of Selma. The Raven Distillery was projected to have an ethanol production cost of \$1.43 per gallon using cull fruit collected from local fruit packing sheds at no cost. About 150 tons per day of this feedstock, diverted from their normal disposal at the county sanitary landfill, were identified as available. However, this feedstock source was seasonal, requiring other supplemental feedstocks to sustain plant operation during winter months. The seasonal nature of feedstocks had the effect of increasing cost beyond the original estimate, due to the need to purchase supplemental feedstocks, such as waste molasses, which added as much as \$0.36 per gallon to the ethanol production cost.

The Raven Distillery began producing ethanol in October 1981 and continued in operation for approximately an 18-month period. The use of the cull fruit feedstock, besides the seasonal availability limitation, created an odor problem for neighboring residents. This problem, plus the marginal economics of plant operation, especially with the higher cost of using the molasses feedstock, ultimately led to shutdown of the plant. When the Energy Commission's contract for support of the project expired and the operators were unable to fulfill contract repayment terms, the plant equipment was

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eventually auctioned off as partial satisfaction of the project's financial obligation to the State.

More recently, in 1997, the Energy Commission collaborated with the National Renewable Energy Laboratory to investigate potential biomass-to-ethanol production in San Joaquin County through the STEP 2 Sustainable Technology Energy Partnership Project. The study participants included the University of California, Davis, California Institute of Food and Agricultural Research and Waste Energy Integrated Systems, a private company pursuing an advanced ethanol production process.

The STEP 2 study resulted in preliminary conceptual design data for a biomass ethanol demonstration plant, including a feedstock availability report, bench-scale ethanol production process testing and other process-related research. Four categories of feedstocks were examined, including mixed waste paper, yard waste and agricultural residues, waste wood and food processing waste.⁽¹⁶⁾

The California Department of Food and Agriculture has also conducted ethanol production feasibility and demonstration programs. One of these programs, the California Alcohol Fuel Plant Design Competition, resulted in 17 submitted designs for farm-scale ethanol production facilities using various agricultural feedstocks. Three finalist projects were constructed and their performance was monitored. The winning design, the Gildred/Butterfield Fuel Ethanol Plant near Paso Robles, received a \$50,000 award in exchange for a report detailing the specifications, construction, operation and performance of the facility (17). The plant, with an estimated production capacity of about 70,000 gallons per year, operated for a period of time in the early 1980s using barley, wheat and other agricultural feedstocks.

The California Department of Food and Agriculture also conducted an Energy and Chemical Feedstock Crop Demonstration Program to examine the potential for production of fuels, chemicals and other petroleum substitute products from California crops. This program, initiated in 1990, undertook demonstrations with four crops -- sweet sorghum, kenaf, canola and lupine.

In all, 22 field demonstrations, along with supporting laboratory analyses were conducted to determine energy production or industrial product potential from these crops. Sweet sorghum and kenaf are two potential energy crops that could be successful as part of California's agricultural production system.⁽¹⁸⁾

The California Integrated Waste Management Board recently undertook a feasibility study of alternative methods of utilizing various types of agricultural and forestry residues, including application as feedstock for ethanol production. The resulting report generally outlines the potential for producing ethanol from different types of residual materials, while also identifying a number of other commercial applications for such products.⁽¹⁹⁾

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Other organizations have also conducted investigations of the feasibility of various biomass-to-ethanol concepts applicable in California. A recent example is a study sponsored by National Renewable Energy Laboratory examining both stand-alone and co-located ethanol/electricity production facilities designed to use forest residue feedstocks. Process designs, heat and material balances, process flow diagrams, and capital and operating costs were developed for 20 million gallons per year facilities assumed to be located at Martell in Amador County, the site of an existing biomass electric power plant.⁽²⁰⁾

Proposed Ethanol Projects in California

In the 1990s, California has witnessed renewed interest in ethanol production, with several new biomass-to-ethanol projects in the planning and development stages. These proposed projects, with production capacities ranging from 12 to 23 million gallons per year of ethanol, all intend to use some type of waste or residue feedstocks and employ advanced production processes to produce ethanol, electricity and other co-products. None of these projects, each briefly described below, is yet firmly committed to begin construction.

Gridley Ethanol Project

BC International Corporation, of Dedham, Massachusetts, is pursuing development of a biomass-to-ethanol facility near Oroville, in Butte County. The Corporation has a proprietary patented processing technology for producing ethanol. The Gridley plant, located in the center of the state's rice-growing region, intends to use rice straw as its primary feedstock. The traditional practice of burning rice straw is being phased out under California legislation, creating interest in alternative applications for this residue, including ethanol production. Wood residues from area orchards, forests and mills would provide supplemental feedstocks for this 20 million gallons per year capacity plant.

The proposed plant site is adjacent to an existing biomass electric power plant, offering the potential to combine electricity generation and ethanol production from the same biomass feedstocks. BC International Corporation's first project of this type is under development at a former petroleum refinery and grain-to-ethanol plant site at Jennings, Louisiana, where sugar cane residues will be the feedstock. BC International Corporation is completing the financing arrangements for the Jennings project, expected to cost \$90 million and require 18 months for retrofitting the existing plant.

The Gridley project would be BC International's second commercial ethanol venture, following the Jennings project. Both the Energy Commission and the U.S. Department of Energy have provided early funding support to develop the Gridley project, of which the City of Gridley would be a major partner and operator.

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Collins Pine Ethanol Project

BCI and the Collins Companies, a timber firm, are planning another biomass-to-ethanol plant at an existing biomass electric power plant site at Chester, in Plumas County. A study team have completed a feasibility study of this proposed 23 million gallons per year capacity facility, which would use forest thinnings and wood wastes as feedstock.⁽²¹⁾ The team was headed by the Quincy Library Group, with participants including the Energy Commission, National Renewable Energy Laboratory, University of California, Davis, California Institute of Food and Agricultural Research, the Plumas Corporation and TSS Consultants.

The Quincy Library Group is a forum for California environmental organizations, county officials and timber industry groups seeking solutions to the accumulation of excess woody material in the Plumas and Lassen National Forests as a result of continued forest fire suppression. Ethanol production is seen as one attractive option for beneficial application of the forest material that needs to be harvested to lessen the potential for catastrophic wild fires and other related forest health problems. The Energy Commission and U.S. Department of Energy are also funding this project.

Arkenol Ethanol Project

Arkenol Inc., of Mission Viejo, is the project developer for a proposed biomass-to-ethanol plant near Sacramento that would use rice straw and wood wastes as feedstock for its 12 million gallons per year production capacity. Arkenol, affiliated with ARK Energy, an electric power plant developer, has patented ethanol production process technology it is seeking to employ in a number of ethanol plant projects in the U. S. and other countries.

The Sacramento area project was initially planned as a joint project with the Sacramento Municipal Utility District (SMUD), and called for construction of a natural gas-fired electricity cogeneration plant on the same site. However, SMUD is no longer an active participant, and the project is undergoing redesign. The U.S. Department of Energy is providing funding support for this project.

What is Ethanol's Role in California's MTBE Phase-Out?

The potential role of ethanol as an alternative gasoline oxygenate component in California gasoline has been under active investigation. The Energy Commission's studies of MTBE alternatives, which helped lay the groundwork for the Governor's Executive Order intended to phase out MTBE, describe a major potential role for ethanol as an MTBE replacement (8).

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Evaluating Substitutes for MTBE

The establishment of realistic potential to replace MTBE – considering the availability of practicable substitutes, including ethanol – has had a major bearing on the state’s decision to proceed with an expeditious (i.e., 3-year) phase out schedule. Water quality and health-related issues clearly formed the primary impetus for the phase out decision, including key University of California study findings that MTBE poses an environmental threat to groundwater and drinking water (22). Nevertheless, the existence of viable replacement options is fundamental to the success of the phase out, and the contribution of ethanol stands to be an important factor.

The Energy Commission’s MTBE alternatives study examined four different oxygenates listed as approved gasoline additives by the U.S. Environmental Protection Agency (EPA). These are: tertiary butyl alcohol (TBA); ethyl tertiary butyl ether (ETBE); tertiary amyl methyl ether (TAME); and ethanol. All four of these options were also judged to have desirable gasoline blending properties and to offer adequate supply availability, although other factors – including acceptability from an environmental standpoint – were not examined as part of this study. Three MTBE phase out time frames were considered: immediate, intermediate-term (three years), and long-term (six years).

Energy Commission MTBE Alternatives Study – Findings Regarding Ethanol

Among the study’s findings addressing ethanol, particularly those pertinent to the three-year phase-out schedule selected by the Governor’s Executive Order, were:

- Maximum reliance on ethanol as a replacement for MTBE equates with a need for as much as 1.15 billion gallons per year of ethanol by 2003. In addition, up to 2.18 billion gallons per year of new gasoline supply would be needed, because a lower percentage blend of ethanol (6%) was assumed to replace the higher percentage (11%) of MTBE used.
- The higher fuel volatility resulting from ethanol/gasoline blending must be offset by substituting certain gasoline components in order to meet California’s gasoline specifications.
- Sufficient volumes of ethanol are believed to be available to meet this level of new California demand, although the impact on gasoline cost – estimated at 6.1 to 6.7 cents per gallon – would be the highest of any of the alternative oxygenate cases studied. A much lower cost impact (1.9 to 2.5 cents per gallon) was estimated for use of ethanol as a longer-term MTBE replacement.
- Most of the ethanol that would be used in California in an intermediate (three-year) MTBE phase-out would be imported from other parts of the U.S.
- Potential California sources of ethanol will not be a likely contributor to supply within a three-year MTBE phase-out, although some 46 million gallons per year of in-state ethanol production capacity was noted to be in planning stages.

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- New California ethanol production sources that could eventually help supply this demand would benefit from a transportation cost advantage of 10 cents per gallon or more.
- Certain unique handling requirements for ethanol would necessitate investments in California's gasoline distribution infrastructure, expected to require 18 to 24 months to complete and to add about 0.1 cent per gallon to gasoline cost.
- A modest fuel economy penalty due to ethanol's lower energy content is estimated to add about 1 cent per gallon to gasoline cost.

Related California Studies of Ethanol

The Governor's Executive Order acknowledges this potential role for ethanol as an oxygenate replacement for MTBE and directs state agencies to further explore the prospects for ethanol production and use in California. Along with this study of the potential for an in-state biomass-to-ethanol industry, two other studies are underway that will bear on the future of ethanol/gasoline blending in the state. CARB and the State Water Resources Control Board are conducting an environmental fate and transport analysis of ethanol in air, surface water and groundwater. This study will help determine, among other things, whether ethanol used as a gasoline oxygenate does in fact offer an effective solution to the types of water contamination problems associated with MTBE use. The Office of Environmental Health Hazard Assessment is preparing a related analysis of the health risks of ethanol in gasoline, including the products of incomplete combustion and any resulting secondary transformation products. Together, the findings of these studies, along with resolution of the outstanding regulatory issues affecting oxygenated gasoline and ethanol gasoline blending, will establish a clearer outlook for ethanol as part of California's motor fuel supply and demand picture.

What Are California's Near- and Long-Term Ethanol Supply Options?

If California becomes a major growing market for ethanol fuel, potential sources of supply include new in-state production facilities, existing and new production facilities elsewhere in the U.S., and foreign sources.

California in the Overall Ethanol Supply Picture

Any serious consideration of a California state government initiative to foster an in-state biomass-to-ethanol fuel industry must take into account not only the market prospects for this fuel but also the outlook for other potential sources that California-produced ethanol would likely compete with. Most of the remainder of this report is devoted to inventorying the resource potential of various candidate ethanol feedstocks in California, estimating resulting ethanol production potential, and examining the processes, economics and development issues associated with such an industry in the state. New multi-faceted "biorefinery" facilities that would produce ethanol as part of various waste-to-energy problem solving strategies are highlighted. Approaches that would involve

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cultivated energy crop feedstocks are considered. Evaluating the attractiveness and viability of any of these different routes to a California ethanol supply industry requires placing them in the proper context of the overall national and international ethanol supply picture.

Existing Midwest U.S. corn-based supply sources appear to be the likely near- and intermediate-term candidates for supplying any California market for ethanol/gasoline blends emerging from the scheduled phase out of MTBE. Meanwhile, as shown in Table II-2, new ethanol supply projects using corn and other crop feedstocks, as well as some using waste-based feedstocks, are planned in an increasing number of other states. California's current in-state proposals for ethanol production amount to a small increment of this planned U.S. capacity expansion.

Brazil, and perhaps some other ethanol-producing countries, could conceivably supply ethanol to California and other U.S. markets, as in the past. However, Brazilian supply and most other foreign sources, while potentially offering excess supply availability – and competitive prices -- are currently shut out by the U.S. ethanol import tariff.

In the longer term, a growing market demand for ethanol fuel in California could see competing supply sources among in-state waste-based or energy crop-based production, expanded production from traditional corn-based or waste-based production elsewhere in the U.S., or foreign sources. Synthetic ethanol production processes, using natural gas or other hydrocarbon feedstocks, are also being applied and represent a somewhat unknown factor as competitors with biomass-based production.

What Will Determine Which Sources of Ethanol Are Most Competitive?

As with other domestic and international industries, the outlook with respect to which ethanol supply sources will ultimately prove most competitive in the California marketplace rests among a variety of circumstances, some perhaps within California's control, others not. Some of the important factors likely to affect future competition among these different sources include:

- Continuation of the U.S. government's favorable treatment of ethanol from domestic biomass-based sources, thus keeping foreign sources and synthetic production at a competitive disadvantage.
- The advent of possible new California state government policies and actions that favor in-state ethanol production with subsidies or other forms of support or protection.
- Progress with ethanol process technology advancements that reduce the cost and/or increase the efficiencies of using certain types of feedstocks (i.e. wastes and residues) over others.

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- Trends in feedstock cost reduction, including incorporating the value of avoided waste disposal and/or reflecting other currently non-monetized benefits of applying waste or residual feedstocks. Also, market trends in competing beneficial applications of feedstocks.
- Transportation costs from ethanol production locations to ethanol markets and the advent of improved, lower cost technology for ethanol transportation and distribution (e.g. pipelines).
- Market demand factors that affect the relative marketability of ethanol in or near the producing regions versus in more distant markets.
- Fuel quality requirements and the ability of various ethanol process technologies and feedstocks to conform with these requirements.
- Regional differences in the availability, cost and marketability of other transportation energy alternatives.

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CHAPTER III

WASTE BIOMASS RESOURCES IN CALIFORNIA

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III. Waste Biomass Resources In California

Introduction

This chapter defines and describes biomass, waste biomass and residues identified as candidates for ethanol production. In addition, estimates of the physical resource potential in California for various waste and residual biomass categories are discussed. The economic and environmental factors and challenges, including competing markets and disposal options, affecting the viability of ethanol production are also examined.

Utilizing the fermentation process, ethanol can be produced from three main sources:

- Sugar, including sugar cane and sugar beets
- Starch, including grains like corn and wheat
- Cellulose, including trees, paper waste, agricultural residues, etc.

This chapter will focus on the latter category, often generically referred to as biomass.

What is Waste Biomass?

Biomass is a broad term, generally defined as matter produced through photosynthesis consisting of plant materials and agricultural, industrial, and municipal wastes and residues derived therefrom.(1) Biomass is often referred to as *cellulosic* (or *lignocellulosic*) *biomass* to differentiate it from grain-based, starch containing feedstocks and sugars. The term is also descriptive, as biomass contains three primary constituents: cellulose, hemicellulose and lignin, and can contain varying amounts of other compounds (i.e., extractives).

Cellulosic biomass must be highly processed to make available sugars that can be fermented into ethanol, compared to sugars (requiring the least processing) and starches. Because of the extensive processing required for cellulosic materials, it is more costly than processing starches and sugars. The important advantages of cellulosic residues are their relative abundance and potentially low, or even negative cost.

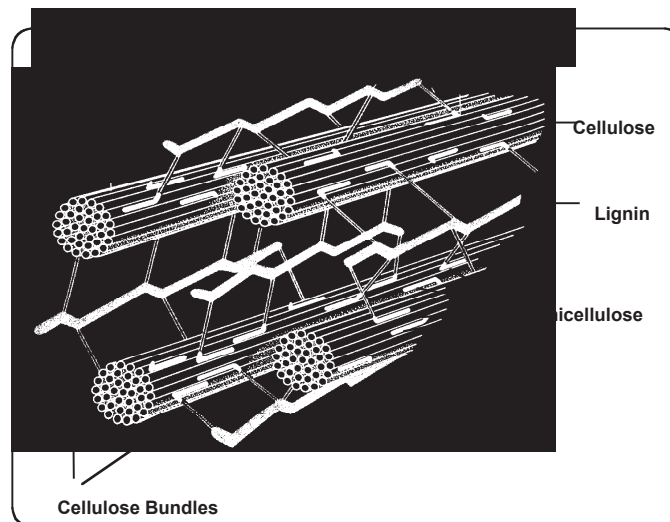
Waste biomass can be considered unwanted products or materials having no further value or use. However, many of the biomass resources discussed in this section are not truly wastes but rather residues. The majority of forest and agricultural materials produced are utilized in one way or another, maintaining some value, and do not end up in solid waste landfills.(2)

Various forms of cellulosic biomass outwardly appear to be very different; however, their chemical makeup is quite similar. About 35% to 50% of the material is cellulose --containing the six-carbon sugar glucose. Another 15% to 30% is hemicellulose -- generally dominated by the five-carbon sugar xylose. The remaining 20% to 30% is composed primarily of lignin, with lesser amounts of extractives, ash and other components.(3) (See Appendix C for additional material)

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Both cellulose and hemicellulose are carbohydrates that can be broken down (hydrolyzed) by enzymes, acids or other compounds to simple sugars. Lignin cannot economically be converted to ethanol, but may be used as a high-energy content boiler fuel for electric power generation and for thermal application such as ethanol production. Potentially, lignin also can be used as a feedstock for chemical synthesis to produce a variety of products, including phenols, aromatics, olefins, surfactants and adhesives.(4, 5)

Figure III-1 (6)



As Figure III-1 shows, the cellulose and hemicellulose are contained in bundle-like structures, with lignin acting like glue to bond the bundles together. The process of converting lignocellulosic biomass to ethanol involves pretreating the biomass to separate the carbohydrate fraction and breaking down these bundles to access the available sugars. The various means of hydrolysis and fermentation are discussed in Chapter V and its Appendix.

Waste Biomass Characterization in California

California has substantial waste biomass resources because of its rich agricultural and forestry resources and its large volume of commercial and municipal solid waste materials. Resources reviewed in this section comprise the following major categories:

- Agricultural residues
- Forest/chaparral residues
- Municipal solid waste

In addition, out of state biomass sources and other potential sources of biomass are discussed briefly.

Collectively, California's estimated gross biomass resource potential for waste residue sources that is convertible to ethanol totals approximately 50.7 million bone dry tons

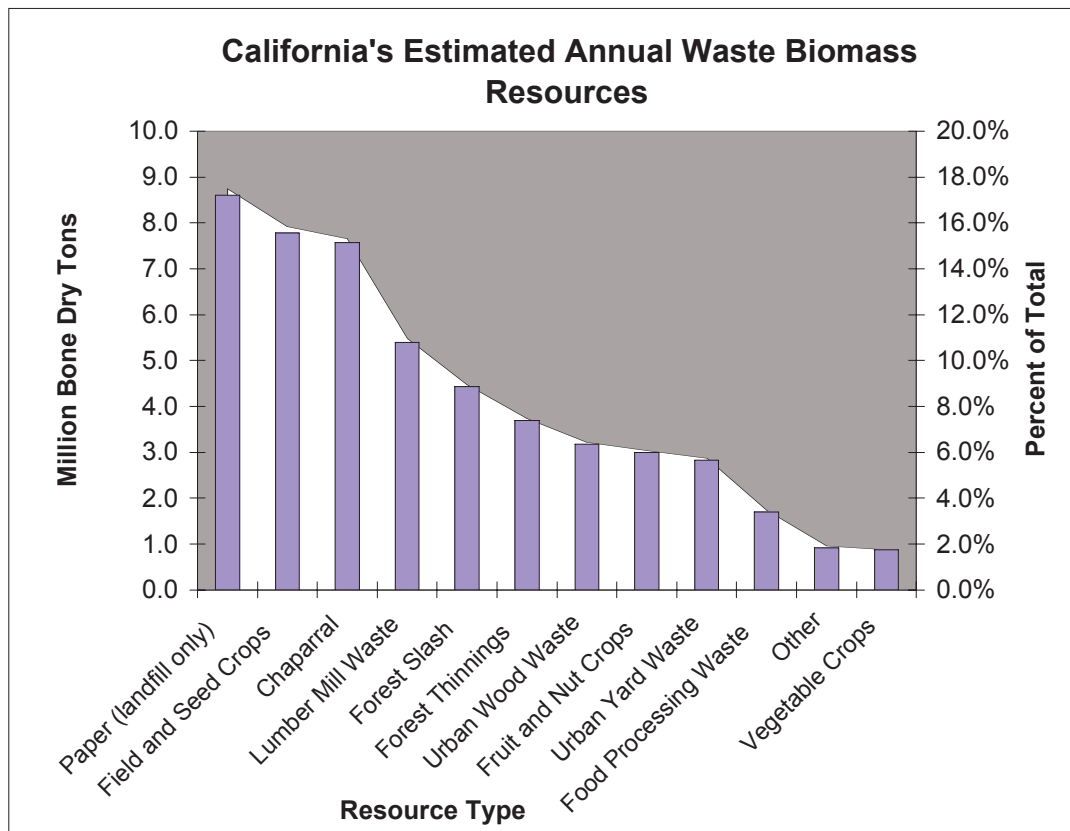
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(bdt). This amount does not include the energy crops or out of state resources that could add significantly to this total.

The gross waste resource estimate includes portions that are currently being used (i.e., for biomass power production, composting, etc.), and materials that at present may be considered uneconomic or problematic to convert to ethanol. Consequently, the amount that can realistically be used today as feedstock is considerably less. Because of the numerous factors that impact cellulosic feedstock viability (collection costs, conversion yields, potential offset costs and other factors) and the limited scope of this study, no attempt has been made in this chapter to develop a specific amount of cost-effective (viable) waste feedstocks. Additional discussions on this follow in Chapters VI and VII.

The characterization of gross waste biomass resources in the state is shown below in Figure III-2 and Table III-1.

Figure III-2 (7)



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Table III-1 shows the estimated waste biomass residues produced annually in California in million bone dry tons. For comparison, estimates include the *CEC Biomass Resource Assessment Study* from 1992 along with the revised numbers that reflect more recent data. (See Appendix C for additional material)

Table III-1

Waste/Residual Biomass Resource Category	Million BDT CEC Biomass Report, 1992*	Million BDT (Revised)	Percent of Total (Revised)
Paper (landfill)	NA	8.7	17.2%
Field and Seed Crops	6.6	7.9	15.6%
Chaparral	7.7	<u>7.7</u>	15.1%
Lumber Mill Waste	5.5	<u>5.5</u>	10.8%
Forest Slash	5.2	4.5	8.9%
Forest Thinnings	1.6	3.8	7.4%
Urban Wood Waste	1.6	3.2	6.4%
Fruit and Nut Crops	1.9	3.0	6.0%
Urban Yard Waste	3.1	2.9	5.7%
Food Processing Waste	1.7	<u>1.7</u>	3.4%
Other [#]	0.9	<u>0.9</u>	1.9%
Vegetable Crops	0.9	0.9	1.7%
Total	36.72	50.7	100.0%

*California Energy Commission, *Biomass Resource Assessment Study*

[#]'Other' category includes small quantities from various sources, such as nursery crop residue

Underlined is the same for both revised and original Energy Commission study of 1992

Agricultural Residues

California has long been the leading agricultural producer in the nation. According to the *1998 California Agricultural Resource Directory*, agricultural production and gross income in 1997 reached \$26.8 billion (including dairy, livestock and poultry). California's agricultural sector is considered one of the most diversified in the world, with no one crop dominating the state's farm economy. Some 350 different crops are recognized in the state; consequently, residues from this sector are substantial.(8)

Currently, much of the residue from California agriculture is incorporated into the soil or used for other purposes. As a result of this and other factors, rice straw and orchard prunings appear to be the principal agricultural residues that are strong candidates for ethanol conversion.

At present, large amounts of rice straw and prunings are burned. While some of the orchard prunings are burned in fields, much is also an important feedstock for the

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biomass power industry in the production of electricity. Some other residues, such as wheat straw, are also now being considered for use as ethanol feedstock material.

Field and Seed Crops

Field and seed crop residues included in this study are from barley, bean, oat, rice, rye, wheat, corn, cotton and sorghum. The biomass residues from field and seed crops are the materials that remain on the ground after harvesting.(9) In the Midwestern US, much research is centered around utilizing corn stover (the corn plant minus the corn) and may be useful for California's corn crop (575,000 acres, equaling 2.7 million bone dry tons of stover). It is rice straw, however, that has attracted great interest in the state for ethanol use. Because of the unique regulatory and societal push to find alternatives to burning rice straw, it will be discussed in detail below.

Rice Straw

Rice straw is plentiful in the Sacramento Valley and, on average, approximately 450,000 acres are devoted annually to rice production.(10) The traditional means of disposal is open field burning, an environmental liability because of the significant amount of undesirable air emissions generated (especially particulates). Resulting legislation (AB 1378, 1991) mandates a reduction in the amount of straw which may be open burned.(11) While more recent legislation has relaxed the time schedule for phasing down open burning (SB 318, 1997), rice straw continues to be considered a viable ethanol feedstock. At the time of this writing, two projects proposal has been developed to utilize rice straw and other feedstocks for ethanol production and are highlighted in section II.

Total available rice straw in the state is approximately 1.5 million bone dry tons (12). The California Legislature has created a tax credit, administered by the state Air Resources Board for rice straw farmers that divert rice straw from burning.

Suitability

Several field and seed crops are well suited to ethanol conversion. While rice straw is the feedstock in this category that is being pursued the most at present, it is not an ideal material to convert. Compared to other forms of lignocellulosic biomass, rice straw has a high ash content, resulting in lower yields.(13) Overall suitability is contingent upon such factors as consistency of its supply, feedstock quality (i.e., free from contaminants), and cost of collection and transport.

Competing Uses

The majority of the residues from field and seed crops are incorporated back into the soil after harvest.(14) By doing so, organic matter and nutrients are returned to the soil. The soil's ability to hold water and resist erosion is enhanced. Although some rice straw is incorporated into the soil, there is concern that continuous soil incorporation could lead to higher incidence of plant disease, so alternatives that remove straw from the field are critical.(15)

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Alternative uses of rice straw also include cattle feed, paper pulp, fiberboard products, straw housing, and power generation. Approximately 30,000 tons/year of rice straw are sold as livestock feed.(16) The off-field alternative uses of rice straw comprise only about 2% of the estimated straw generated annually.

Challenges

Challenges to the use of rice straw for ethanol include the following:

- Difficulty of collecting residues in wet fields
- Lack of demonstrated history converting to ethanol
- Seasonality of feedstock
- Potential for other, more economical alternative uses (e.g., soil incorporation, construction materials, etc.)

Fruit and Nut Crop

The fruit and nut crop residues included in this study are prunings or brush from almond, apple, apricot, avocado, cherry, date, fig, grapefruit, grape, kiwi, lemon, lime, olive, orange, peach, pear, pistachio, plum, prune and walnut trees. Clearing orchards of old or diseased trees is another source of residue. Total residue from fruit and nut crops is about 3.04 million bdt/year.

Suitability

Biomass residues from fruit and nut crops appear to be attractive for ethanol conversion. If the feedstock is relatively free from contaminants, such as dirt, prunings can be a viable ethanol feedstock.

Competing Uses

Much of this resource is either disposed of through open field burning or has use in other industries. As of 1989, approximately 39 percent of the residue were open field burned. In 1990, 330,000 bone dry tons of fruit and nut crop residue was consumed in power combustion facilities. However, because the biomass power industry is using less prunings today, more of this resource could be available for ethanol production. A small portion of the wood produced from fruit and nut trees is also sold as firewood.(17)

Challenges

Challenges to using this category for ethanol feedstock include the following:

- The residue can be contaminated from soil, especially if the material is left in fields for a long period of time
- Like many other agricultural crops, they are seasonal in nature, mainly available from November to March.
- Potentially wet or muddy fields may restrict collection
- Removing a large portion of the residues from the fields/orchards would impact the soil quality where it has been incorporated back into the soil.
- The economics of collecting, chipping and transporting this biomass resource may be costly depending on a number of variables, making much of it uneconomic.

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Vegetable Crop

Vegetable crops included in this report include artichoke, asparagus, cucumber, lettuce, melon, potato, squash and tomato. Total residue from vegetable crops is approximately 860,000 bdt/year. A sizable portion of this resource is incorporated back into the soil. To collect this residue for ethanol use, farmers would have to find it more economically attractive than tilling it back into the soil. Vegetable crop soil incorporation is useful for nutrient replacement, water retention and erosion control. Given the limited amount of this resource, its value to enrich the soil and its wide geographic distribution, vegetable crop residues do not appear to be strong candidates for conversion to ethanol.

Forest Residue

Forest residues are being considered for conversion to ethanol because of the substantial amount of biomass potentially available and because conversion is seen as a partial means of improving forest health. Residues from the forest include branches and small trees left after logging operations, as well as trees collected from thinning operations.

Forestry experts have repeatedly stated that a dangerous situation has developed in forests from decades of fire suppression and other traditional management practices.(18) To prevent forests from burning, fire suppression efforts have caused overgrowth in forests as large numbers of small trees and shrubs increased the density of vegetation and the species mix. Ironically, this in turn has led to increased risk of catastrophic wildfires, which are completely different in nature from natural fires. High intensity fires result, destroying virtually everything in their wake and incinerating the top layer of duff and soil. Furthermore, overstocking of California's forests diminishes wildlife habitat quality and may increase disease in overcrowded tree stands.(19)

To prevent overloading in the forests, mechanical thinning operations clear a portion of the growth and can be used in concert with prescribed burning, a common practice of periodic controlled burnings of forest areas. The forest residue generated from thinning and logging has little use for timber or paper products and must be disposed of through burning or other means. Conversion of forest residues to ethanol and/or electricity, with coproducts, offers an attractive alternative to burning. (See Appendix C for additional material)

According to the Department of Forestry and Fire Protection, California's timber industry yields about \$1 billion annually. Of the state's approximately 40 million acres of forestland, some 13 million acres is commercial timberland that would likely benefit from thinning.(20) The primary trees in this forest environment include Ponderosa Pine, Sugar Pine, Fir, Douglas Fir, Incense Cedar and Redwood.

The United States Forest Service manages approximately one-half of the forest land in the state. According to the US Forest Service, at least 250,000 acres per year of the land under their jurisdiction would benefit from thinning operations in order to realize fully the fire suppression, forest health, and water-yield benefits that are desirable.(21)

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Forest Slash

Forest slash or logging residues are the portions of the trees that remain on the forest floor or on the landing after logging operations have taken place. This material consists mostly of tree branches, tops of trunks, stumps, branches and leaves.

Forest Thinnings

As mentioned earlier, thinning operations are mainly intended to reduce the density of tree stands, thereby reducing the risk of catastrophic wildfires.

Thinning materials are generally not of sufficient quality to be utilized for lumber. The amount of forest thinnings available will likely be higher in the early years of a major forest thinning campaign. Because of this, some forest thinnings estimates are much higher than listed in Table III.1. However, over the long run the amount of thinnings removed from California forests at a sustainable level will be much lower than in the early years.

Lumber Mill Waste

Lumber mill wastes or lumber processing residues consist of the slabs, shavings, trimmings, sawdust, bark end pieces of wood, and log cores that result from the various processing operations occurring in sawmills, pulpmills, and veneer and plywood plants. (23)

Suitability

This biomass feedstock is desirable because of its large and relatively uniform supply. Lumber mill waste, however, has a high percentage of bark, which is not well suited for ethanol conversion. As mentioned above, because much interest has been generated in thinning activities to improve long-term forest health and reduce the potential for catastrophic fires, motivated parties may be willing to pay for removal of unwanted forest vegetation. Depending on the determined value to accomplish this, forest residue conversion may be quite economically viable.

Competing Uses

Much of the forest slash that is collected is consumed by the power industry. In 1990, approximately 30 percent was utilized in this manner. These various forest biomass resources also are incorporated into a variety of wood-based products. These include particleboard, firewood and other building materials. (24)

Challenges

Challenges to using this category for ethanol feedstock include:

- Some environmentally sensitive areas, such as those protecting endangered species, have limited or banned logging activities resulting in decreased forest slash produced.

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- Because most forests are in geographically remote locations, the distance to transport the residue is limiting.
- Costs for collecting, chipping and transporting forest residue is costly and will likely need to be subsidized to compete with other feedstocks (by land owners, fire suppression agencies, etc.).

Chaparral Residue

Chaparral consists of heavily branched dwarf shrubs of various species that grow mainly in arid locations in Southern California.(25) If not removed, chaparral will eventually be consumed by wildfires in California. Chaparral is now, and is expected to continue to be, thinned periodically to minimize fire risk. Although little commercial use is made of chaparral, the brush lands surrounding many of Southern California's homes in the wildland areas could be a source of biomass for ethanol production.

Chaparral in Southern California is comprised of several species. They include examples such as: Chemise, Ceanothus, Scrub Oak, and others.(26) Within California, estimates vary widely from 5 million acres to as high as 20 million acres of chaparral lands. This area has apparently not received extensive study. For the purposes here, we are assuming that there are nearly eight million acres of chaparral in the state, equating to 7.7 million bone dry tons.

Suitability

Chaparral appears to be an unlikely feedstock candidate for ethanol production. Besides being difficult, and therefore costly, to harvest, ethanol conversion yields are generally low. These species tend to be high in extractives and lignin, and low in cellulose and hemicellulose. Only if the collection of chaparral can be sufficiently subsidized (for example, by landowners or fire suppression agencies) will chaparral look economically viable.

Competing Uses

No competing uses appear to exist for chaparral.

Challenges

Challenges to using this category for ethanol feedstock include:

- High cost of collecting and transporting the material
- Much of the available chaparral is found on steep slopes, making it difficult or impossible to collect
- When converted to ethanol, chaparral is expected to produce higher air emissions and water effluents than other studied biomass feedstocks.(27)

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Municipal Solid Waste

In 1998, California disposed of approximately 37.5 million tons of waste in landfills (and diverted more than 33 percent of its waste).(28) Table III-2 shows the composition of California's municipal solid waste stream.(29)

Table III-2

Commercial/Industrial Waste Stream		Residential Waste Stream	
Paper	43%	Organics	43%
Organics	30%	Paper	31%
Plastics	10%	Plastics	7%
Metal	7%	Other	6%
Glass	4%	Glass	5%
Construction & Demolition	3%	Metal	4%
Other	3%	Construction & Demolition	4%
TOTAL	100%	TOTAL	100%

Source: California Integrated Waste Management Board.

Areas in **bold** are potential ethanol feedstocks

Municipal solid waste (MSW) streams that can be potentially diverted for ethanol production include the following:

- paper waste (e.g., newspapers and magazines)
- urban wood waste (including wood processing waste)
- urban yard wastes – or green waste (such as grass clippings)
- and other organic materials.

The motivating factors to convert MSW to ethanol include legislative directives to reduce landfill material, the potential to collect sizable tipping fees (a charge levied by refuse collection sites, which can help offset conversion costs), significant year-round resource availability, and the benefit of having a centralized collection and processing site.

Facilities that process MSW, separating recyclable material, compost material, etc., may be attractive sites to collocate with an ethanol production unit. Where tipping fees are sufficiently high, the economics may be compelling enough to develop such a waste-processing/fuel-production plant.

The Masada Corporation is developing an MSW-to-ethanol plant in Orange County, New York utilizing this concept. In California, projects such as the STEP-2 project in the San Joaquin Valley (see Chapter II) have also investigated converting MSW to ethanol.

Urban Yard Waste

Grass clippings, leaves, tree and bush trimmings from both residential and commercial properties make up urban yard waste. The CIWMB estimates that 6.4 million tons (about 2.9 bone dry tons) of yard waste were disposed of in the state during 1998.

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Suitability

Urban yard waste appears to be a viable feedstock candidate within the boundaries of certain conditions. These conditions include the need for a uniform and clean waste stream, and appropriate paper type.

Competing Uses

A large portion of urban yard waste is incorporated into the soil or is used for compost material. In addition, some urban yard waste is incinerated or disposed of by open field burning.

Challenges

Challenges to using this category for ethanol feedstock include:

- Contamination of yard waste (dirt, garbage, etc.)
- Seasonal availability
- Potential technical difficulties in the conversion process
- Does not store well because of high decomposition rate

Urban Wood Waste

Suitability

Urban wood waste appears to be an attractive feedstock for ethanol and has been an important feedstock for the biomass power industry.

Competing Uses

Unlike many other waste biomass sources, urban wood waste has existing markets. These include power use, production of particleboard, composting, and others. As mentioned earlier, the biomass power industry has been challenged by the deregulation of the electricity markets and has accordingly reduced production, making additional supplies potentially available for ethanol production.

Challenges

Challenges to using this category for ethanol feedstock include:

- Possible contamination of wood
- Large variability of wood type and quality
- Competing uses as described above
- Availability

Paper Waste

One of California's largest available resources is mixed waste paper. Approximately 14 million tons were generated in 1997. Of this total, approximately 9.5 million tons (8.7 million bone dry tons) were disposed of at landfills, with the remainder reused through various recycling processes.(30) The relative attractiveness of this waste resource is dependent on several variables. These variables include the paper waste fraction at a

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particular material recovery facility, the type of paper material available, the quality of material, and other factors. Where waste streams are adequately separated, whether up front by the consumer or at the plant, paper waste and other feedstocks can be collected for processing to ethanol with relative ease.

Suitability

Although the mixed waste paper resources in the state are substantial, it is unclear how viable this resource is for ethanol production because of contamination and other issues. Consequently, unlike forest and agricultural residues, mixed waste paper has not attracted the same level of interest within the state.

Competing Uses

Competing uses include recycling, pulp manufacturing, power production, and other uses.

Challenges

Challenges to using this category for ethanol feedstock include:

- The difficulty of converting certain paper types (e.g., high gloss papers contain compounds that may make conversion difficult) (31)
- Problems associated with paper that are contaminated or contain inks that can cause difficulties in the conversion process
- Potential cost of separating clean paper waste
- Competing use markets that are well developed and may grow as efforts are made to find alternatives to sending waste materials to landfills
- Regulatory barriers that discourage the conversion of MSW to ethanol (i.e., AB 939 that limits the credit to “transform” waste rather than recycle, etc.)

Other Waste Biomass Sources

Other California Waste Biomass Sources

Other sources of waste biomass feedstock also exist, but have not been included in the gross biomass resource potential (Table III-1) because of their generally low conversion yields or other factors that make their viability marginal at best. Livestock manure is such an example. The Energy Commission’s past work in assessing biomass resources for the power industry concluded that approximately 11.9 million bone dry tons exist in the state (1992). However, the carbohydrate fraction of manure is low, resulting in poor conversion yields and rendering it comparatively non-economic for this application. Further, the high moisture content and chemical makeup of manure may present additional and potentially costly steps in the conversion process. Manure appears to be better suited to other energy conversion processes, including anaerobic digestion for methane gas production. However, additional investigation should be pursued before consideration of manure for ethanol is completely ruled out.

Out-of-State Resources

Beyond the state’s own domestic resources, it is possible that biomass could be imported from outside the state and converted to ethanol. While this scenario seems unlikely at the

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present, it deserves mention. The most likely resource would be forest material coming from the Pacific Northwest. Oregon's forest, covers about 28 million of the state's 62 million-acre land base. Approximately 65,000 Oregonians work in sawmills, plywood plants, pulp and paper manufacturing operations, logging and trucking companies, and wood furniture manufacturing facilities.(32) Residues from logging, forest thinning and sawmills are significant. Furthermore, Oregon faces similar forest health problems as Northern California, as evidenced by this statement from the Oregon Department of Forestry:

It's estimated that 25 percent of Oregon's forests are either dead or dying from insects, disease and prolonged drought. That's almost 7 million acres of forests, most of that is located in central and northeast Oregon. ...the combined effect of the dead and dying trees and exclusion of fire have resulted in an unprecedented accumulation of fuel and the potential for unstoppable catastrophic wildfires. The state believes that a careful but intensive forest management approach is needed, especially on federal lands which have been particularly hard hit. Long-term actions should include thinning of stands to improve tree spacing and providing a healthy and diverse mix of tree species that are tolerant to drought, insects and fire.(33)

Oregon's substantial forests provide the potential for a waste residue stream that could be utilized in areas near the California/Oregon border.

The suitability, competing uses and challenges for out of state biomass resources are essentially the same as those highlighted in the forest residue section. The principle difference appears to be the expected higher costs due to transporting distances and possible restrictions for interstate commerce.

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CHAPTER IV

BIOMASS CROP RESOURCE POTENTIAL IN CALIFORNIA

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IV. Biomass Crop Resource Potential in California

Introduction

This Chapter examines the potential for producing ethanol in California from biomass energy crops. It identifies different types of crops that are candidate feedstocks for ethanol production, reviews previous studies of the potential for energy crop-based ethanol production in the state, and discusses key factors that affect the prospects for realizing this potential.

Why Consider Energy Crops for Ethanol Production?

Much of the recent focus on new biomass-to-ethanol production potential centers around the types of waste- and residue-based feedstock sources covered in the previous chapter. The waste disposal and environmental issues associated with these types of feedstocks, and the expected economic advantages of beneficial energy applications of such materials, make them the leading candidates for biomass-to-ethanol projects being proposed for the near-term.

Biomass energy crops, cultivated, harvested and supplied directly for their energy value, represent another approach to supplying feedstocks for ethanol production. Most appraisals of the longer-term, larger-scale potential for ethanol as an alternative fuel view cultivated energy crops as the ultimate feedstocks, after the more limited resource opportunities for waste and residual feedstocks are captured. Furthermore, advanced ethanol production process technologies currently under development have application to many crop-based as well as waste-based feedstocks. This raises possibilities for future ethanol producing facilities capable of accommodating feedstocks from both types of sources.

What Types of Energy Crops Can Be Used to Make Ethanol?

Two general categories of energy crops could be adapted to producing ethanol -- multi-purpose crops that have other agricultural markets and “dedicated” energy crops, selected and cultivated solely for energy production. Multi-purpose crops, such as the familiar examples of corn in the U.S. and sugar cane in Brazil, represent almost all of the world’s ethanol production to date. The future outlook for ethanol production from energy crops is more concentrated on crops selected specifically for and dedicated primarily to this purpose, including those most adaptable to advanced cellulosic conversion processes.

Despite its standing as the number one agricultural-producing state in the U.S., California has yet to be extensively studied for its potential for growing energy crops to produce

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Table IV-1: Candidate Energy Crops

<u>Field Crops</u>		
Rape seed	Soybean	Spring barley
Rye	Sunflower	Hemp
Sugar beet	Triticale	Cardoon
Miscanthus	Kenaf	Jersusalem artichoke
Sweet sorghum	Buchina	Broom
False flax	Corn cockle	White mustard
Knotweed	Spartina	Cuphea
Potato	Prickly pear	Guar
Sweet Potato	Corn or maize	Pearl millet
Flax	Buffalo gourd	Sugar cane
Amaranth	Grindelia	Rice
Fodder beet	Meadowfoam	Wild tobacco
Lupine	Wheat	Alfalfa
Sericia lespedeza	Casuarina	
<u>Perennial Grasses</u>		
Switchgrass	Intermediate wheatgrass	Orchard grass
Reed canary grass	Napier grass	Bermuda grass
Sudan grass	Elephant grass	
Eucalyptus	Poplar	Willow
Alder	Birch	Sycamore
Tumbleweed	Cottonwood	Silver maple
Black Locust	Sweetgum	
<u>Aquaculture crops</u>		
Kelp	Water hyacinth	Cattail
Algae	Reed	

Bold entries are crops that have been looked at for California application

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ethanol fuel. The California Department of Food and Agriculture (CDFA) has conducted limited investigations of this potential, supplemented by other studies on a national and regional scale. Continuing research and limited application of energy crop technologies nationally and internationally provide further information to help examine the prospects for crop-based approaches to supplying ethanol.

Table IV-1 is a listing of identified energy crop candidates, divided into four categories: annual field crops, perennial grasses, woody crops, and aquaculture crops. The suitability of individual crops for different energy applications varies, with direct combustion for heat or electricity generation, extraction of vegetable oil fuels, and conversion to ethanol comprising the major options. The geographical and climatic adaptability of these various energy crops also varies from region to region. Thus, only selected crops will be optimally suitable for cultivation in any candidate growing region. Resource requirements, including the necessary land acreage and water supply, further affect the applicability of individual energy crops to particular regions.

To date, specific energy crops best suited for cultivation for ethanol production in California have not been definitively studied. However, the California Department of Food and Agriculture has examined some of the energy crops listed in Table IV-1. These include field crops such as sweet sorghum, perennial grasses such as elephant grass and tree crops such as eucalyptus. Certain types of crops have generally been discounted from serious consideration for California energy crop application. Corn, for example, although currently the source of most U.S. ethanol production, is not considered economically viable for ethanol production in California due to irrigation water requirements.

Aquaculture crops are another relatively little-studied category of energy crops of potential interest in California. The energy potential of certain types of aquatic crops grown in wetlands, lakes, bays and oceans may offer particular opportunities for the state, given its extensive aquatic access and temperate climate. Aquaculture energy crop candidates that have received at least limited research attention include species of algae and kelp, and plants such as water hyacinth and cattail, some of which are believed to offer higher rates of production than land-based crops. However, specific aquaculture crops considered highly suitable for ethanol production have yet to be developed.

What Is the Extent of California Energy Crop Potential in California?

The California Department of Food and Agriculture's various assessments over the years have concluded that opportunities exist to develop crop-based ethanol production in California as part of the state's overall agricultural industry. Dedicated energy crop plantations could provide for in-state fuel production while providing a means to diversify agricultural markets, help stabilize the agricultural economy and contribute to rural economic development. Among the specific candidate energy crops identified by CDFA are sweet sorghum, kenaf, Jerusalem artichoke, buffalo gourd, industrial potatoes, fodder beets, elephant grass, switchgrass, sericea lespedeza, eucalyptus, poplar, and Casuarina (1).

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Figure IV-1 shows the existing (1997) distribution of California's 28 million acres of agricultural lands, which comprise roughly one-fourth of the state's total land area. While no reliable estimates have been developed of the ultimate potential for energy crop development in the state, CDFA has provided limited estimates of ethanol production potential based on simply adapting small fractions of this in-use agricultural acreage. Devoting 10 percent of the current 10 million acres of the cropland fraction of agricultural lands to production of energy crops such as sweet sorghum, fodder beets or industrial potatoes would support production of an estimated 500 million gallons of ethanol per year.

A similar volume of ethanol production is estimated to be supported by use of 10 per cent of productive timberland for tree crops. Larger estimates of ethanol production potential would result from expanding the analysis to include use of agricultural lands not currently applied to crop production, as well as additional land not presently devoted to agriculture.

Beyond the above simple estimates based on fractions of existing agricultural land use, the question of how much ethanol could ultimately be produced from energy crops in the state becomes somewhat open-ended. A fundamental estimate, based on the assumption of an annual ethanol yield of 600 gallons per acre, suggests that a land area roughly equivalent to the state's current total agricultural land use shown in Figure IV-1 (28 million acres) would provide the ethanol fuel equivalent of today's California highway gasoline demand of 13 billion gallons per year. This can be compared with the existing U.S. corn-based ethanol production of about 1.4 billion gallons per year (about 1.1 billion gasoline-equivalent gallons), employing about 4 million acres of corn crop.

Estimates of surplus cropland in the U.S. -- including an average of 60 million acres per year idled by federal programs such as the Conservation Reserve Program -- indicate significant potential to expand energy crop production without significant displacement of food crops.(2)

Are There Any Previous Studies of Ethanol Production from Energy Crops?

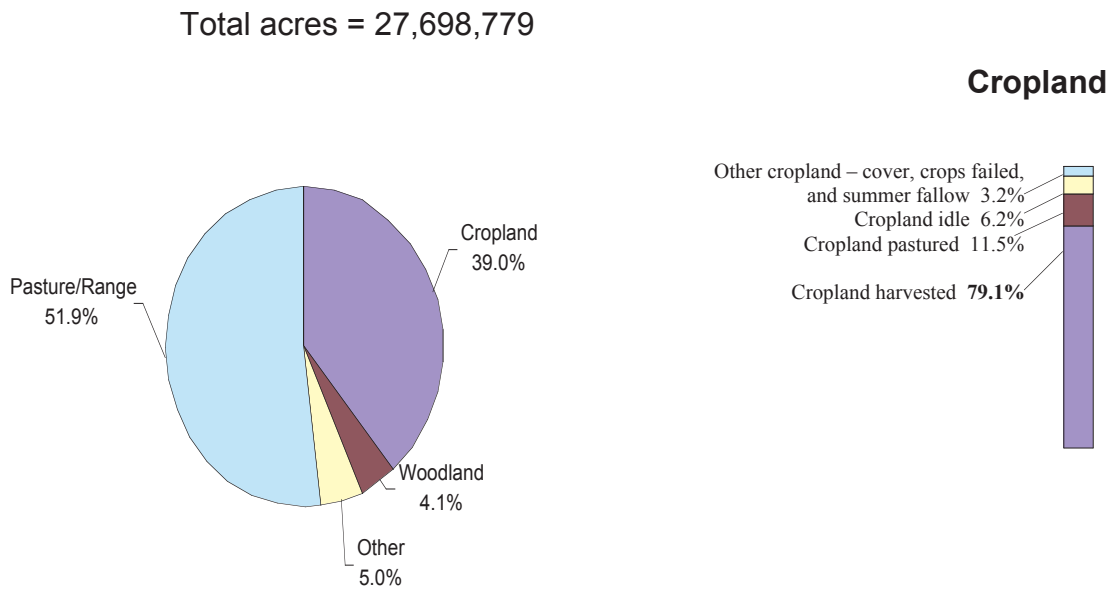
The California Department of Food and Agriculture has investigated ethanol production from some selected potential California energy crops in more detail as part of its Energy and Chemical Feedstock Crop Demonstration Program, initiated in 1990 (3). This program included a series of field demonstrations and laboratory studies involving a variety of identified energy crops. Two of these, sweet sorghum and kenaf, were found to have desirable characteristics for potential crop-based ethanol production in California. The CDFA program's findings for these two crops are summarized as follow:

Sweet Sorghum

Demonstration plantations of sweet sorghum varieties were grown in 1990, 1991 and 1992 by twelve different farmers in eight California counties, ranging from southern San

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FIGURE IV-1: CALIFORNIA AGRICULTURAL LAND USE – 1997



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1997 CENSUS OF AGRICULTURE

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Joaquin County, to the central coast, to the northern Sacramento Valley, to the high plains of Lassen County. Yields ranged from 1.6 to 13.5 bdt/acre, with an average of 7.6 bdt/acre. Total costs of production up to harvest ranged from \$32 to \$90/bdt, with irrigation cost accounting for from \$44 to \$100/acre, or about 15 per cent of total production cost.

Evaluation of both ethanol-only production and ethanol/electricity co-production scenarios yielded the following energy potential estimates for this crop: ethanol production only – 145 to 1,228 gal/acre (690 avg.); co-production – 72 to 658 gal/ acre (355 avg.) ethanol and 884 to 7,109 Kwh/acre (4,100 avg.) electricity. Inputs of required production energy were viewed as favorable, with fertilizer and herbicide inputs also reportedly low and pesticide input zero. About one-half the irrigation water requirements of corn under similar conditions was reported.

Kenaf

This crop was studied as a candidate for cultivation in California's cotton growing regions. With yields up to 11 bdt/acre, kenaf was determined to be more expensive to produce than sweet sorghum. Kenaf has a variety of non-energy markets with higher values, with applications ranging from carpet backing to poultry litter. A scenario of secondary ethanol production from kenaf used as poultry litter showed a feedstock cost of \$15/bdt and an ethanol production potential of 34 gal/ton, resulting in a feedstock cost of \$0.44/gal without co-product credit.

The program's conclusions noted that these crops are agronomically and technically feasible. However, several factors were noted that must be addressed before these and other energy and industrial crops are to become economically feasible: (1) continued agricultural development to assure higher and more consistent yields; (2) development of more resource-efficient biomass production systems; (3) further development of post-harvest systems; and (4) public policy that assures pricing of energy sources to include externalities including environmental impacts and impacts to local, state and national economies.

Other Studies

Others have looked at the potential for producing ethanol from tree crops such as eucalyptus and poplar. One non-site-specific analysis considered poplar as the feedstock for a large-scale ethanol production facility employing advanced processing technology (4).

This study of a large hypothetical facility, comparable in size to the largest existing corn-to-ethanol plant – with a capacity of more than 300 million gallons per year – considers the ethanol production potential from poplar feedstock produced from a land area within a 50 mile radius, corresponding to the maximum transport distance for a typical corn-based plant. In this case, (optimistic) assumptions of 10 tons of harvested feedstock per acre per year and 100 gallons of ethanol production per ton of feedstock result in an estimated production potential of 5 billion gallons per year.

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The U.S. Department of Energy's Oak Ridge National Laboratory, as part of its Bioenergy Feedstock Development Program, conducts analysis of energy crop potential in the U.S., including regional applicability of specific energy crops.(5) Over 125 tree and nonwoody crop species have been screened as potential energy crops by this program, participants in which include 30 universities, 5 U.S. Department of Agriculture research units, and 4 private companies.

The program employs a model to identify U.S. locations where favorable conditions for energy crop production exist. Poplar has been identified as an attractive energy crop candidate for the Pacific Northwest, and the program is sponsoring several studies related to poplar cultivation in this region. Other regional program activities involving both tree crops and perennial grasses are ongoing in the South Central and Southeast Regions, the Northeast Region, and the North Central Region of the country.

What Are the Factors Affecting Crop-Based Ethanol Development?

While crop-based ethanol production may offer more ultimate long-term resource potential, the future of this approach in California is, in some ways, subject to more uncertainty than that of waste- and residue-based approaches. Even though crop-based sources represent virtually all current world ethanol production and will supply any near-term markets of ethanol in the state, no plans are in evidence for production of ethanol from California-grown energy crops. Planned expansion of the U.S. corn-to-ethanol industry is unlikely to extend to California, and the only active proposals to develop new ethanol production capacity in the state are the planned waste-based projects described in an earlier section.

Some aspects of crop-based ethanol production likely to have an effect on whether or not this course proves viable for future application in California are briefly discussed as follow:

Economics

Feedstock costs are a key driver of overall ethanol fuel economics, prompting a heavy focus on ethanol production approaches estimated to have low-cost or no-cost feedstock sources, usually waste- or residue-based approaches. Thus, the ability of crop-based ethanol feedstock candidates to achieve feedstock costs competitive with waste- and residue-based sources will be an important determinant of the viability of crop-based production. Some progress appears to be being made in this respect. Meanwhile, competing markets for residual feedstocks, and increasing costs of acquiring adequate waste feedstock supplies may serve to improve the competitiveness of crop-based feedstocks. Improvements in ethanol production process economics may represent a neutral factor between waste- or residual based and crop-based feedstocks but could improve the overall market picture for ethanol and thus accelerate the need to expand supply beyond that available from waste or residual feedstocks. Trends in agricultural

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economics, including government policies to continue or add support for energy produced from the farming sector, will also play a role.

Land Use

Dedication of significant areas of usable land to any form of energy production always raises a difficult issue, moreso when agricultural acreage is at stake. Use of waste and residual feedstocks for ethanol production have an obvious advantage in this respect, since no significant new land use requirements are usually involved. Any proposals for growing new energy crops for ethanol production are likely to reopen the traditional “food versus fuel” arguments that waste-based approaches avoid. Nevertheless, modern agriculture exhibits increasing overall productivity, as well as the ability to produce a multiplicity of food, energy and other products, as well-illustrated by the U.S. corn-to-ethanol industry. An increased public understanding of the benefits of integrating energy production with agricultural production could serve to dispel the traditional food versus fuel controversy and allow more serious consideration of crop-based ethanol options. Such options may prove particularly attractive where they can be effectively applied on marginally productive or set-aside lands.

Irrigation Water

Water supply for agricultural irrigation is a sensitive issue in California, especially where new water rights or expanded usage for new acreage or crops is involved. Waste and residual feedstocks, as well as crop-based feedstocks grown in other regions with adequate precipitation, seem to have a clear advantage in this regard to potential crop-based ethanol feedstocks grown in California that require expensive and difficult to obtain irrigation water. Still, the advent of drought-tolerant low water-requiring energy crops suggests the potential to at least partly overcome this constraint, as would development of suitable aquaculture energy crops. Furthermore, some current California crops with high water requirements that face diminishing markets or declining market values might be partially replaceable with energy crops with a net decrease in water application.

Environmental Impacts

Various environmental impacts that have come to be associated with conventional agriculture – soil erosion, pesticide and fertilizer runoff, air pollution, etc. – are general impediments to any new or expanded farming practice, energy crops included. However, compared with most existing farming practices, cultivation of certain energy crops may offer considerably reduced environmental impacts. Reduced fertilizer requirements and reduced or eliminated pesticide application are two important characteristics noted for some crops, such as sweet sorghum, that have been studied as potential ethanol feedstocks in California. Some energy crops, either as replacements for or rotated with conventional crops, may also offer soil enhancement and erosion control benefits.

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Global Climate Change

Ethanol fuel may offer one of the most promising options for reducing the transportation sector's contributions to atmospheric carbon dioxide greenhouse gas build-up. If global climate change mitigation becomes an increasing societal priority, both the extent of ethanol production and use and the selection of ethanol feedstocks and production processes could be affected. Evaluations of fuel cycle carbon emission characteristics have revealed significant differences among various current and prospective means of producing ethanol, ranging from minimal carbon-reducing benefit to near total elimination of net carbon release. Thus, the selection of an ethanol fuel cycle, including feedstock, processing technology and types of energy inputs to the cycle, can be a major determinant of the resulting greenhouse gas implications, with certain crop-based cycles potentially yielding the best effect. Also, relying on ethanol fuel as a substantial part of a global warming solution would equate with development of the larger resource potential of crop-based feedstocks.

Market Demand

Interwoven with several of the above factors is the overall outlook for ethanol fuel demand, as affected by ethanol's own progress as an alternative fuel technology, but also by cost and supply trends of other competing conventional and alternative fuels. Should any combination of prevailing factors serve to create sustained growth of an ethanol fuel market beyond near-term requirements for replacing MTBE, crop-based production will ultimately be needed to meet this demand.

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CHAPTER V

BIOMASS CONVERSION

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V. Biomass Conversion Processes

Introduction

This chapter describes the most competitive current technologies and probable improvements to increase the rate of conversion, yields and efficiency of production of ethanol, electricity, and co-products from urban, agricultural, and forest wastes. These improvements will result in lower costs per gallon of ethanol produced in 2003 and beyond.

The following sections survey the various technologies for converting biomass, including the more established approaches, research on methods to improve them, and possible features of a mature biorefining industry. (See Appendix D for more details on all of these topics.)

Background

Large-scale production costs for biomass-based products depend primarily on the delivered cost of the raw material and on the costs of the conversion processes.

Feedstocks for ethanol production generally cost less, on a per-ton basis, than crude oil. Biomass conversion industries can be cost-competitive with petroleum-based industries if research, development, and demonstrations significantly reduce processing costs (Ref. V.1). Major cost reductions seem most likely in two areas: the chemical pretreatment of biomass wastes and the biological conversion of these wastes.

A biorefinery is the most economical approach to converting biomass to ethanol because other products from the biomass, such as electricity, process steam, and chemical co-products, lower the cost of producing ethanol. This approach will ensure an integrated biomass industry that is environmentally and economically sustainable.

For example, hemicelluloses in waste biomass can be converted into ethanol to meet transportation needs. Celluloses can be converted into ethanol or into chemicals, pulp or fibers. Lignin can serve as a high-energy fuel for electricity and steam production. Extractives can produce a wide variety of commodity and high-value chemicals.

Steps to Convert Biomass to Ethanol

This section outlines the processes used to convert biomass to ethanol. (For more details, see Appendix D). Both this section and the Appendix utilize historical and current technical information provided by the National Renewable Energy Laboratory (NREL) in its 1999 Bioethanol Strategic Roadmap (Ref. V.2).

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In a typical biomass conversion to ethanol, the biomass might undergo the following:

Pretreatment Step

First, the wastes are pretreated. Pretreatment makes the biomass structure more accessible to the subsequent steps.

The biomass is reduced in size by cutting and milling. It may also be washed. It is then subjected to physical, chemical, or biological pretreatment, or to a combination of these (Ref. V.3).

Chemical pretreatments to make the biomass more digestible have received the most research; these pretreatments utilize dilute acid, alkaline, organic solvent, ammonia, sulfur dioxide, carbon dioxide, or other chemicals.

Hydrolysis Step

In concentrated acid hydrolysis, the cellulose and hemicellulose are converted to sugars with concentrated sulfuric acid and diluted with water at modest temperatures.

Dilute acid hydrolysis is both the oldest technology for converting biomass to ethanol and also the approach that has received the most research and commercial interest.

Enzymatic hydrolysis is the most recent of these methods and the one that depends most on biological developments.

Facilities Using Hydrolysis to Convert Biomass to Ethanol and Other Products

Two facilities plan to use concentrated acid hydrolysis to convert biomass to ethanol. For the Sacramento Ethanol Partners project in Rio Linda, California, Arkenol plans to use rice straw to produce ethanol and to recover amorphous silica from the rice straw as a co-product. The Masada Resource Group project in Orange County, New York, plans to use municipal solid waste and sludge to produce ethanol.

BC International and the Department of Energy, Office of Fuel Development, have formed a cost-shared partnership to develop a 20 million gallons per year biomass-to-ethanol plant in Jennings, Louisiana using dilute acid hydrolysis to recover sugar from bagasse (sugar cane wastes) and rice hulls. A proprietary, genetically-engineered organism will ferment the sugars from bagasse and rice hulls to ethanol.

BC International also presently plans to use two-stage dilute sulfuric acid technology with rice straw and wood wastes as the feedstocks in the Gridley biomass-to-ethanol facility collocated with the Pacific Oroville Power Plant. If enzymatic hydrolysis (discussed later in this chapter) proves reliable and cost-effective, then one stage of dilute acid pretreatment followed by enzymatic hydrolysis will be considered as an alternative.

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The Collins Pine/BC International project proposal for Chester, California, is also collocated with an electric power plant. The plan is to pretreat the softwood feedstocks with dilute sulfuric acid, followed by enzymatic hydrolysis and fermentation of sugars to ethanol using proprietary bacterial enzymes. The softwood extractives will be converted to two or three chemical co-products: the beginnings of a California forest waste biorefinery.

Tembec and Georgia Pacific operate sulfite pulp mills that use dilute acid hydrolysis to dissolve hemicellulose and lignin from wood and produce specialty cellulose pulp. The hexose sugars in the spent sulfite stream are fermented to ethanol. The lignin is either burned to produce process steam or converted to value-added products such as dispersing agents or animal feed binders.

Fermentation Step

In the fermentation step, sugars are converted by yeast into ethanol. This production step may be performed separately or combined with enzymatic hydrolysis.

Hydrolysis Combined with Fermentation

Enzymatic hydrolysis combined with fermentation converts pretreated biomass into sugars by one of several methods described in Appendix D.

Interest in enzymatic hydrolysis of cellulose began in the South Pacific during World War II, when an organism now called *Trichoderma reesei* destroyed cotton clothing and tents. The U.S. Army laboratory at Natick, Massachusetts set out to understand the action of this fungus and to harness it. They found that the fungus produces enzymes now called “cellulases” because of their effectiveness in hydrolyzing cellulose. Subsequent generations of cellulases have been developed with increased effectiveness great enough to achieve commercial applications.

Petro-Canada signed an agreement in 1997 with Iogen Corporation to co-fund development of a biomass-to-ethanol technology based on Iogen’s proprietary cellulase technology, and with the aid of the Canadian government, to begin construction of a demonstration plant in 1999. As previously mentioned, BC International will begin operation of their plant in Jennings, LA using dilute acid hydrolysis technology, but they will allow for the utilization of enzymatic hydrolysis when cellulase production becomes cost-effective for their facility.

Cellulase production (for enzymatic hydrolysis) and ethanol production in a single reactor vessel by a single microbial community is known as consolidated bioprocessing, or as direct microbial conversion (DMC). If the required technological advances can be achieved through genetic engineering followed by cost reductions through improved practice, then consolidated bioprocessing in a form suitable for a biorefinery could serve

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as a model for what might be achieved long-term in the California biomass-to-ethanol industry.

An example, given in Reference V.4 for a large consolidated bioprocessing facility operating on poplar as a dedicated energy crop, suggests an eventual cost around 50 cents per gallon for producing ethanol, using advanced methods in a mature industry.

Gasification Followed by Fermentation

In gasification-fermentation, the biomass is first gasified, converting the biomass into a mixture of smaller molecules that includes carbon monoxide, carbon dioxide and hydrogen. The molecules are then reassembled into ethanol by fast fermentation processes.

Bioengineering Resources, Inc has developed a technology that combines gasification followed by fermentation to produce ethanol from a variety of biomass wastes. Plans are underway to pilot the technology as a step toward commercialization. The yields can be high (a figure of 136 gallons of ethanol per ton of feedstock is projected) because all of the major biomass fractions, hemicellulose, cellulose, *and* lignin, can be converted to ethanol.

Grain- or Sugar-Based Ethanol Production

This section summarizes the processes used to convert grains and sugars into ethanol. These processes are used by the Midwest ethanol industry, which converts corn kernels to ethanol.

The Midwest corn-to-ethanol industry is a major competitor to a growing California biomass-to-ethanol industry and also has major lessons to teach it. If California biomass is to compete effectively with Midwest corn and with petroleum as sources of transportation fuel, we must learn the lessons that these more mature industries have to teach.

In converting corn to ethanol, many of these lessons are explicit in the differences between the two major commercial methods, dry milling and wet milling. The following descriptions draw heavily on Ref. V.5, “Ethanol from Corn: Technology and Economics” by Elander and Putsche, Chapter 10 in the *Handbook on Bioethanol: Production and Utilization*.

Corn is composed of starch, sugar, oil, fiber, protein and ash. The starch and sugar constitute the 70%-75% of the corn kernel that can be converted to ethanol. In dry milling, the entire corn kernel passes through the process used to convert the starch to ethanol. The solid residue containing protein is recovered for use as an animal feed known as distillers dried grain with solubles (DDGS).

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The more modern wet milling approach first separates the corn kernel into its major components such as corn oil, corn gluten meal, corn gluten feed, and starch. All major components are converted into materials responsive to current market demand, and in particular, starch is converted into ethanol and other products. A wet milling plant is thus a corn-to-ethanol biorefinery.

Dry milling produces a higher yield of ethanol per bushel of corn than wet milling, but fewer value-added products. Dry milling is less capital-intensive, but also less profitable than wet milling. Several improvements are possible, including more efficient processing of the hemicelluloses, and possibly even conversion of dry mills to modified wet mills (to be described later).

Wet milling now represents about 60% of all ethanol production. Corn is steeped to loosen the germ and hull fiber and separate the kernel into its components. The germ, hulls and fiber are combined to make corn gluten feed (CGF). The gluten from the kernel makes corn gluten meal, a high protein animal feed. The starch is converted to sugars that are fermented to ethanol. Other possible co-products include corn steep liquor, fiber, dextrose, high fructose syrup and corn oil. Interestingly, corn oil is the highest valued co-product while ethanol is the most abundant.

Large-scale wet milling plants can now produce ethanol from corn at a cost up to 19 cents per gallon less than a dry milling facility. The steeping process can be further improved and the co-products recovered with higher efficiency. Processing of corn kernels to ethanol and co-products by either dry milling or wet milling is subject to the high and fluctuating costs of the feedstock.

In a variation of this process, modified wet milling eliminates some of the capital investment required for complete corn fractionation. Compared to standard wet milling, modified wet milling requires less capital investment, but still retains a significant value for co-products.

Technologies for improving the corn-to-ethanol processes are being investigated. They include using corn residues, bacterial fermentation, improved fermentor design, semi-permeable membranes, improved distillation, and co-product development. The agricultural residue, called corn stover (cobs, leaves, and stalk), is not yet processed to ethanol, but if and when this is done, transportation costs from the Midwest to California will remain a significant economic factor.

The technology of yeast fermentation from sugars such as molasses is simpler, involving the dilution of the molasses, introduction of yeast, fermentation, and distillation. A product of the sugar industry, molasses is widely used for fermentation to ethanol.

Thus, ethanol production from sugars is simpler than that from starches, which in turn is simpler than that from waste biomass. But sugars and starches have a higher economic value as food, while waste biomass has a low, sometimes negative, economic value, and the major costs presently associated with its use as a feedstock for conversion to ethanol and co-products are often those of collection and transportation.

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Ethanol Production in a Biorefinery

This section discusses some key issues regarding ethanol production in a biorefinery along with some examples of biorefineries in California. (Appendix D provides a more detailed discussion of these topics.)

In a biorefinery, ethanol and a variety of other products such as electricity and chemicals, are produced. A biorefinery helps to ensure that a biomass-to-ethanol industry in California is economically and environmentally sustainable.

A California biomass-to-ethanol industry must compete with Midwest corn-to-ethanol and with petroleum; both of these industries rely on a slate of products to maintain their present cost and pricing structure. A corn-to-ethanol company producing only ethanol, or a petroleum corporation producing only gasoline for automobiles, would not survive.

In these more mature industries, the cost of the delivered feedstock ranges between 65%-70% of the total production costs. Thus, the feedstock must be optimally used, and the production of the various products must be adapted to meet current market demands. A California waste biomass-to-ethanol industry must make the best economic uses of the chemical components of its waste feedstocks. The industry should grow to adapt its output of various products to market demand.

In some projects, this process has already begun. Two California projects will be collocated with existing electric power plants. These are the Collins Pine project in Chester, California and the Gridley project in Oroville, California.

The biomass plant will buy power from the electric plant and will supply the electric plant with lignin as a high-energy fuel. Each is a customer of the other. This synergy from cogeneration results in reduced capital and operating costs that enable both plants to be more competitive. The next step is to produce along with ethanol, a slate of other chemical products. This step will be taken by the Arkenol project in Rio Linda, California and also by the Collins Pine project.

The Arkenol project will produce amorphous silica from the rice straws as a co-product, using the Arkenol concentrated acid process on rice residues and wood wastes as the feedstocks.

The Collins Pine project will produce several chemicals (as yet unspecified) from the extractives as co-products, using California softwoods and lumber mill wastes as feedstocks. These co-products can significantly improve the process economics, while separating off substances to facilitate further processing of the carbohydrate streams.

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Technology Improvements in a Mature Industry

This section recaps the improvements in the process steps outlined above that will help develop a profitable biomass to ethanol industry in California. (Appendix D provides more details.)

Specifically, these improvements are in the following four areas: 1) improved pretreatment, 2) increasing use of genetically-engineered organisms for hydrolysis and fermentation of biomass, 3) integrating process steps to reduce capital and operating costs, and 4) producing ethanol from biomass in a biorefinery.

Within these primary trends, there are a variety of alternative, often complementary, research and development paths toward the goal of very low cost production of ethanol from waste biomass.

Some of these are reduction of milling costs, pretreatments to make cellulose more reactive, a low-cost method for recycling cellulase, and higher temperature fermentation. A breakthrough in one of these areas has the potential to reduce difficulties in other areas.

Approaches that reduce the cost of making biomass fermentable have the largest economic impact. Consolidated bioprocessing is one preferred approach because “it offers the potential for a streamlined process that takes full advantage of the power of biotechnology for efficient and low-cost catalysis” (Ref. V.6). This path requires the development, through genetic engineering, of robust microorganisms that perform many functions in a single reactor.

What are the potential cost reductions for ethanol production that may result from the anticipated improvements in technology when these are incorporated into a mature biomass industry? In the literature, there are several fairly consistent estimates by respected scientists, engineers, and research organizations.

The National Renewable Energy Laboratory has set cost reduction targets of about 50 cents per gallon for technology cost savings by 2005, and about 60 cents per gallon by 2010 (Ref. V.7). On this or a somewhat longer time-scale, Drs. Lynd, Elander, and Wyman (Ref. V.3) estimate production costs of about 52 cents per gallon using consolidated bioprocessing with poplar trees as the energy crop for a very large facility.

In comparison, California has the advantage of using much lower-cost (waste) feedstocks, but the state may not be able to realize the advantages of scale accruing to larger plants (greater than 100 million gallons per year production). In petroleum and corn processing, about 65%-70% of the total production costs are attributable to feedstocks, so in this respect, the use of waste biomass is a significant advantage.

The above improvements in production costs do not include the effects of producing the ethanol in a biorefinery that benefits from the production of electricity and added-value co-products. To estimate the impact of biorefining on a mature industry, we use values

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provided in Ref. V.5 and by Dr. Katzen in Ref. V.8 for the advantage in unit production costs of (more capital-intensive) wet-milling of corn, compared to the older dry-milling process.

Wet-milling facilities are corn biorefineries. They can produce ethanol from corn at a cost 10 cents to 19 cents per gallon less than dry-milling facilities that produce only ethanol and DDGS. When a single figure is required, 15 cents per gallon will be used in this study as the estimated average, long-term reduction in cost of producing ethanol, when the ethanol production is accomplished within a biorefinery, but a range of zero to 30 cents per gallon cost reduction is plausible.

Chapter VII of this report provides more detail on the economic estimates of ethanol production from waste biomass in California.

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CHAPTER VI

BIOMASS-TO-ETHANOL PRODUCTION POTENTIAL IN CALIFORNIA

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VI. Biomass-to-Ethanol Production Potential in California

Introduction

This chapter combines the prior results for biomass resource potential from Chapter III and those from ethanol production processes of Chapter V to develop estimates of the maximum ethanol production potential in California. This maximum production potential in California is well over 3 billion gallons of ethanol per year, but it is limited by many factors, including the accessibility of capital. The key question is: can one billion gallons of this potential be realized by effectively addressing the key technological, economic, and institutional issues?

Several major production considerations cause the practical total to be considerably less than the maximum calculated. These include geographic factors, plant size, infrastructure and distribution requirements, markets for electric power and co-products, and other identifiable supports and constraints that will affect the size, profitability, and long-term viability of biomass-to-ethanol industries in California.

One scenario for the growth of biomass-to-ethanol production in California is presented, but considering the large number of important unknowns, it is only an example.

Estimating the Ethanol Production Potential

The production potential is defined as the amount of ethanol that can be produced annually in California by converting all waste biomass into ethanol transportation fuel. This is calculated by multiplying the total bone dry tons (bdt) of waste biomass by the gallons of ethanol that can be produced from each bdt of waste.

The most direct way to obtain an overall estimate of the annual ethanol production potential in California is to multiply the total resource potential of approximately 50.7 million bone dry tons (bdt) of biomass (from Table III-1) by a conversion efficiency averaged over the plant operations for the various feedstocks and processes.

The average yield assumed for near- to mid-term conversions is 70 gallons of ethanol, plus electricity and co-products, produced from one bdt of biomass. Multiplying 50.7 million bdt of waste biomass by the assumed conversion efficiency of 70 gal/bdt (approximately 64% conversion efficiency) gives 3.5 billion gallons as the estimated theoretical annual production potential. The major factors that will reduce this total are the collection, production, distribution, economic and institutional considerations that will be listed in subsequent sections of this chapter.

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Table VI-1 Ethanol Production Potential* of Waste Biomass Resources in California (based on yields provided by M. Yancey and A. Aden of NREL)

Waste/Residual Biomass Resource Category	Million BDT (Annual)	Near-Term Yield** (gal/BDT)	Near-Term Production Potential (millions of gallons)	Mid/Far-Term Yield*** (gal/BDT)	Mid/Far-Term Production Potential (millions of gallons)
Paper (landfill)	8.74	63.0	550.6	95.3	832.5
Field and Seed Crops	7.90	55.1	435.0	85.5	667.3
Chaparral	7.65	24.0	183.7	36.3	277.4
Lumber Mill Waste	5.47	59.5	325.4	82.5	451.3
Forest Slash	4.50	66.5	299.1	94.8	426.5
Urban Wood Waste	3.23	45.6	147.1	66.6	215.0
Fruit and Nut Crops	3.04	49.0	149.1	72.8	221.4
Urban Yard Waste	2.88	45.6	131.2	66.6	191.7
Forest Thinnings	3.75	66.5	249.4	94.8	355.5
Food Processing Waste	1.74	43.6	75.9	64.4	112.0
Other	0.94	54.6	51.3	81.2	76.3
Vegetable Crops	0.86	43.6	37.5	64.4	55.3
Total	50.70	51.5 (avg)	2,636	76.0 (avg)	3,882

* This assumes collection, delivery and processing of all the biomass with conversion to ethanol at the yields shown for each Resource Category, for each of the two time periods.

** Near-term yields are based on current NREL 2-stage dilute acid experiments and models. (Assumptions are tabulated in Appendix E)

*** Mid/far-term yields are based on NREL projections for performance of the SSCF (1-stage dilute acid/1-stage enzymatic hydrolysis) process. (Assumptions are tabulated in Appendix E)

More detailed calculations of the maximum annual ethanol production potential in California are shown in Table VI-1, based on near-term and mid-to-long-term yields provided by M. Yancey and A. Aden of NREL for each of the individual biomass Resource Categories in Table VI-1. The process assumptions used for the near-term calculations are based on NREL's current experiments and modeling of the 2-stage dilute acid conversion process. The assumptions used to calculate the mid-to-long-term yields are based on NREL projections for the SSCF process (1-stage sulfuric acid, followed by enzymatic hydrolysis with simultaneous cofermentation). These assumptions are tabulated in Appendix E.

The results, given in Table VI-1, are 2.6 billion gallons for the near-term, and 3.9 billion gallons for mid-to-long-term ethanol production potential from California waste biomass,

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bracketing the 3.5 billion gallons near-to-mid-term theoretical maximum estimated above.

These more detailed figures are both large enough that the conclusion remains the same. The technological (collection, transportation, processing, distribution), economic (financing, competition, markets for products), and institutional (laws, regulations, incentives, agencies, interest groups) factors to be discussed in this section and later sections of this report, will determine the economically and environmentally sustainable size and profitability of a California biomass-to-ethanol industry.

The following sections of this chapter discuss some of the important considerations that affect the scope, distribution, and profitability of biomass-to-ethanol conversion facilities in California.

Geographic Distribution

Proximity to available sources of waste biomass feedstocks will be a major consideration in the siting of California biomass-to-ethanol conversion facilities, such as collocation with existing municipal solid waste collection and processing sites. Collocation with existing electric power generation facilities will be another. Proximity to markets is expected to be a weaker factor.

Most of the biorefineries operating on forest slash, forest thinnings, and lumber mill waste would be located in the northern portion of the state. The Northeastern California Ethanol Manufacturing Feasibility Study (Ref. VI-1), also known as the Quincy Library Group (QLG) Study, provides much more detail on the relevant site selection criteria. Facilities to convert rice straw and hulls, walnut and almond shells, orchard prunings, and other agricultural wastes will be located throughout the state, with many of them in the San Joaquin Valley, some near food processing plants. Biomass-to-ethanol plants using municipal solid wastes (MSW) as their feedstocks will most frequently be located near existing MRFs (Materials Recovery Facilities), large volume processing/transfer facilities, or landfills.

Data on active locations for collection and processing of all of these categories of waste biomass were obtained with the assistance of staff members of the California Integrated Waste Management Board. Some of the many possible sites for supplying waste biomass to biorefineries are tabulated in Appendix F.

Biomass-to-ethanol plants using one or more components of the municipal solid waste (MSW) stream as their feedstocks will be geographically associated with the existing MSW collection, transfer, and processing infrastructure. Biorefineries are most likely to be located in close proximity to MSW hubs that provide both on-site sorting capabilities and a sufficient volume or flow of materials to guarantee fulfillment of feedstock needs.

In urban areas of the state, such hubs are typically associated with large volume transfer and processing stations, or material recovery facilities (MRFs), where MSW materials are

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aggregated on a regional basis, and then sorted and redistributed to a wide variety of commodity and residual disposal markets.

As collocation hosts, urban MRF/transfer stations can segregate a dedicated stream of cellulosic materials to the biorefinery partner appropriately tailored to ethanol production technologies. Feedstock suitable for acid hydrolysis technologies is currently available in separated and preprocessed form at many large MRFs throughout the state, particularly MRFs containing process lines that receive select paper-rich commercial loads. The residual waste streams from such sorting operations, which are currently transported to landfill, typically contains a high percentage of feedstock-quality waste paper.

The MRF/biorefinery collocation scenario greatly enhances the potential of MSW for ethanol production, since the collection and processing infrastructure are already in place and separately funded. This makes it possible for biorefinery developers to partner with MRF operators by offering them a "tipping fee" at an adjacent ethanol plant which is less than the cost to transport and dispose of these same materials at competing landfills. In this collocation scenario, both partners benefit: the MRF operator by reduced or avoided disposal costs, and the biorefinery operator by negative feedstock costs.

In less populated areas of the state, or on urban fringes, major MSW hubs may be located at regional landfills. Such disposal facilities may also emerge in the future as biorefinery hosts where they can both attract and supply sufficient pre-sorted cellulosic feedstocks to an on-site ethanol plant, such as through preferred disposal rates for segregated loads at the landfill gate. Other potential economic benefits to the biorefinery partner may be available, such as the provision of landfill gas for boiler fuel, or the provision of electrical power or steam from landfill gas cogeneration plants.

Non-combustion technologies for biomass conversion are defined in current state law in the same category with incineration, as "transformation" technologies, and are thereby limited to a maximum of 10% diversion credit toward meeting the mandated 50% recycling goal. If the non-combustion biomass-to-ethanol technologies were defined as "diversion" and made eligible for full diversion/recycling credits, this would provide a widely-dispersed selection of economically-attractive candidate sites for which the collection and separation infrastructures are in place. Some of these are listed in Appendix F.

For conversion of forest wastes, six specific sites in Northern California were identified by the Quincy Library Group Study (Ref. VI.1) for further characterization. The proposed locations are associated with existing or former sawmill sites in the towns of Anderson, Chester, Greenville, Loyalton, Martell and Westwood, California. All of the sites except Greenville have access to existing biomass power plants and are large enough to host a new biomass-to-ethanol facility with adequate space for the storage of feedstock.

The Collins Pine facility at Chester in Plumas County was chosen in a California Energy Commission Public Interested Energy Research competition for detailed investigation,

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probably leading to its development by Collins Pine Company and BC International to produce ethanol, electricity, and chemical co-products. The site at Martell in Sacramento County is presently undergoing further study.

Production Facilities

The first biomass-to-ethanol conversion facilities planned for California are expected to process agricultural wastes (SEP) and forest wastes (Collins Pine). Many will be collocated with existing electrical generation plants that supply them power, and to which they provide lignin-based fuels, to reduce both capital and operating costs. They will produce co-products in order to lower their "net feedstock cost" for producing ethanol, and to increase the profitability of their operations. Subsequent plants will be collocated with MRFs, other waste collection facilities, and near food processing plants.

These initial plants are likely to be relatively small, producing around 20 million gallons of ethanol per year. Some mid-term plants may be larger, perhaps 50 million gallons per year, and in the long-term, mature California industry, a few facilities could approach the size of modern corn-to-ethanol wet-milling operations in the Midwest that produce over 200 million gallons annually. This increase in plant size may be expected as the financial community gains greater confidence in the industry and in the increased profitability of larger operations. A limitation to this growth in plant size will be the capability to supply the larger plants with feedstocks collected economically from greater distances.

There are now in operation in California 28 biomass power plants owned by independent power producers. Many of these might benefit from synergies with collocated biomass-to-ethanol facilities. Most of these biomass power plants were built after passage of the Federal Public Utilities Regulatory Policy Act (PURPA) in 1978 and energy policies in California (Standard Offer contracts, etc.) provided suitable incentives. The industry grew to provide about 750 MWe in 1990.

Restructuring of the electric utility industry caused the utilities to buy out many of the Standard Offer contracts, reducing the biomass operating capacity to about 550 MWe. Most of the remaining facilities are now nearing contract "cliffs", after which they will receive about 4.5 cents/kWhr instead of the 12 cents/kWhr (on average) that they received earlier. AB 1890 and SB 90 provide additional support to biomass power of up to 1.5 cents/kWhr through the year 2001. The survival of this industry after that time is uncertain.

One option being considered actively by California as biomass energy industry (Ref. VI-2) is to integrate the power plants with biomass-to-ethanol facilities to realize the significant synergies that result, as planned by Collins Pine in Chester, California and the Gridley project in Oroville, California. This co-operation provides the biomass power plant a major customer for its steam and electricity, and the ethanol facility with the capabilities and the infrastructure of an operating power plant, including access to cheaper steam and electricity than would otherwise be available. The biomass-to-ethanol facility gains a customer for its lignin, to be used as a fuel for the power plant. These

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synergies improve the cost of operations of both portions of the combined facilities and help to assure their survival.

The statewide potential for collocation of biomass-to-ethanol facilities with biomass power plants is large in terms of biomass utilization and ethanol production. If ethanol facilities were collocated with all 28 operating biomass power plants and the ethanol plants produced enough lignin to fire the approximately 550 MWe of operating capacity, 12 million dry tons of biomass would be utilized annually. This “best case” scenario would result in approximately 900 million gallons of annual ethanol production from the collocated biomass-to-ethanol facilities. It is not likely that ethanol facilities will be collocated with every biomass power plant in the state or that these facilities will produce ethanol only, but this brief analysis shows the potential for collocation opportunities.

The plants will likely be biorefineries producing ethanol, electricity and other value-added co-products, with production capabilities that can respond to future markets. This approach will be necessary to compete successfully in the near- and mid-term with corn-to-ethanol wet mills, that are themselves biorefineries, and in the long-term with petroleum-based fuels and chemicals. These biorefineries must be assured of reliable, long-term, economically-priced sources of feedstock. The use of waste feedstocks is a major advantage of the California-based industry, in comparison with facilities utilizing corn or petroleum as feedstocks.

Adequate water must also be available for processing the biomass to ethanol and co-products. Air quality, water quality, and land use regulations must be complied with. Roads must exist for transportation of feedstocks and supplies to the plant, and for the distribution of products to customers. Electric transmission systems should be in place for the export of power.

The production capacities of the earliest California biomass-to-ethanol plants will be determined most strongly by the ability to obtain capital, and second, by the ability to obtain assurances for reliable, long-term supplies of low-cost feedstocks. The first may be affected by state actions, such as incentives or loan guarantees; the second will be determined by the types of feedstocks employed and the arrangements that can be made with the owners. In the case of forest wastes, this might include the US Forest Service; for agricultural wastes, the supplier may be a regional farming cooperative; and for urban wastes, a waste management company or Materials Recovery Facility operator.

A combination of sources and feedstock types will often be used, for example, rice straw and wood wastes. Feedstock collection and delivery are elements of major importance in the plant economics, both because the cost of delivered feedstocks is often the single largest cost element, and because the scale of operations is determined by the size of the daily supply. The daily supply of feedstock, in turn, depends on the methods for harvesting, collecting, transporting, and storing the cellulosic material. This may be simpler for municipal solid wastes, MSW, where most of the collection and transportation infrastructure is already in place.

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Infrastructure and Distribution

A biomass conversion plant is the central element in the larger ethanol production system, with many other necessary functions preceding conversion, operating at the site, and following the conversion of biomass into ethanol and co-products.

Waste feedstocks must be delivered reliably to the plant. When long-term feedstock sources are established, the required collection, storage, and transportation mechanisms must be put in place.

Sources of electricity and process heat (perhaps from a collocated power plant), water for processing and cooling, chemical reagents and supplies, facilities for waste material and energy disposal, on-site and external roads, and the necessary environmental approvals must all be in place to support on-going operations.

Contracts will have been written for sales of the plant's products including the acceptance conditions (specifications) and delivery schedules. Since the biomass conversion facilities produce ethanol and co-products for which market demand and prices will vary, contracting may be a dynamic process, just as it is for corn- and petroleum-based product slates. The facilities for product distribution to local, regional, and more distant clients must be established.

Specific examples include facilities owned by the oil companies for blending ethanol with gasoline, for transporting the blend to the gasoline stations, and for distribution to consumers at the pump. All of these elements are part of the infrastructure necessary to support a California-wide biomass-to-ethanol industry.

Harvesting, collection, pre-processing, transport, and storage of feedstocks prior to conversion at the plant are among the most demanding aspects of the operation. Using forest wastes as feedstock requires that specialized equipment such as feller-bunchers and grapple-skidders be employed efficiently to keep costs down. Use of agricultural wastes requires dealing with the seasonality of harvests and provision of, or access to, adequate storage for stubble, shells, or other residue.

Processing of municipal solid wastes will usually require the least additional infrastructure, because systems for the transportation and collection of wastes at authorized locations are in operation. The separation of metals, glass, and plastics from biomass feedstocks, such as wood wastes, paper wastes, and yard wastes has often already been accomplished, and can be done at additional sites for a negotiated price.

Some insight into the complexities, and also the opportunities that exist in harvesting and handling operations, is provided in a grant application (Ref. VI-3) to the US Department of Agriculture by Prof. Bryan Jenkins of UC Davis.

This document, entitled "Harvesting and Handling Rice Straw for Off-Field Utilization", lists a variety of individual operations, such as raking, swathing, baling, threshing,

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“roadsiding”, hauling (including loading and unloading), storing, grinding, and cubing, not all used in one field. Several may be used in combination to provide optimum methods for in-field, central, or satellite processing. The choice depends on many factors including rice variety, straw moisture, field moisture, straw-to-grain ratio, equipment availability, utilization requirements, and of course, weather.

Many inefficiencies result from existing practices. For example, "Stack wagons often roadside bales in stacks that are too tall for a single truckload. Consequent restacking must occur which decreases productivity. In other examples, bale roadsiding equipment had high speed capability but slow hydraulic system performance that delayed the machine when picking up bales. These are areas in which some small and readily made equipment modifications might have significant impacts on capacity."

It is not surprising that practices developed for the harvesting and handling of grain are non-optimum for the harvesting and handling of straw. If the transport and sale of rice field residues to biorefineries become a significant economic and environmental consideration to rice growers, residue management will evolve to become more economically and environmentally beneficial to the producers and the surrounding communities. Furthermore, equipment manufacturers may be motivated to develop specialized equipment for this growing market.

Storage of agricultural residues is an important issue for biomass-to-ethanol plants that operate year-round, because of the seasonal harvesting of the agricultural produce that leaves the residues. The residues used as biomass feedstocks may be left in the fields or collected for storage off-site. It is usually unsatisfactory to leave them uncovered in the fields for more than a few weeks, because the accumulation of moisture may cause deterioration and sometimes spontaneous combustion. The more common practice will be to cover the material with tarps or store it in barns for several months, until it is transported to a conversion facility.

Major elements of infrastructure at the conversion site include roads, water, and power. Availability of water is an especially important consideration because many of the steps in biomass conversion deal with dilute streams, containing relatively small quantities of material in much larger volumes of water. Process improvements, such as water recycle, would eventually reduce water usage.

Power production, conversion, and transmission facilities must also be available to support plant operations and to export any excess power to the regional grid. The availability of an existing power plant has been the determining factor in locating some of the first facilities (Collins Pine in Chester, and the Gridley project in Oroville). This is both because of the reduction in capital required for construction, and for the synergies in operation resulting from cooperation in supply of lignin-based fuel (from the ethanol to the electric plant) and power (from the electric to the ethanol plant).

Important elements of infrastructure must be in place for the sale and distribution of the ethanol, electricity and co-products. The electricity may be used internally or exported to

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the regional grid. Development of contracts for the acceptance of ethanol, commodity and specialty chemicals requires a marketing effort that is broader and more adaptive than for the single product, ethanol.

There are also features of the operation of a biorefinery related to those established by specialty chemical and pharmaceutical manufacturers for the marketing and sale of small quantities of high-value products. Functions may evolve analogous to those required for efficient drug discovery, as biorefiners begin to explore the economic possibilities available from the various chemical fractions of their feedstocks.

Constraints and Challenges

In the usual biomass parlance, the technological, economic, and institutional factors that affect the viability of individual biomass-to-ethanol projects and the expansion of the industry are referred to as barriers. Here they are considered simply as constraints and challenges, conditions of the real world that must be understood, evaluated, and adapted to or modified, if California is to realize an economically and environmentally sustainable biomass-to-ethanol industry. Here is a list of some of these factors, as they are outlined in Ref. VI-4.

Technological Considerations: feedstock characteristics, seasonal availability, residue collection; feedstock production, storage, and processing; process scale-up; material erosion and corrosion.

Economic Considerations: production costs, capital costs, enzyme costs, costs of delivered feedstocks, competing markets for residues, and costs of environmental compliance.

Although some references include environmental considerations among the barriers, they will in the long-run be advantageous for conversion of waste biomass to ethanol, as compared to fossil fuels and other forms of non-renewable energy usage.

Environmental Considerations include: effects on the soil, ecological impacts, air emissions, water usage, wastewater treatment, environmental permitting, endangered species, harvesting agricultural residues, and ash disposal.

Institutional Considerations: incentives to producers and users, permitting requirements, emission offset requirements, availability of residues on a long-term basis, cooperation among agencies, long-term supportive state regulations.

Some of the more significant economic and institutional constraints are:

(1) Access to bank loans, which could be alleviated by legislative authorization of 10- to 15-year loan guarantees for construction and operation of biomass-to-ethanol facilities.

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- (2) Access to MSW, which could be alleviated by redefining non-combustion technologies to receive full credit toward the goal of 50% diversion.
- (3) Need for a long-term, unified, supportive state biomass-to-ethanol policy, perhaps coordinated through a consortium of the responsible agencies.
- (4) Need for reliable, long-term contracts for supplies of low-cost waste biomass feedstocks, a problem that might solve itself, if the above constraints were mitigated.

A Scenario

Much has been said in this chapter and elsewhere in this report about the conditions that would nurture the growth of a biomass-to-ethanol industry in California. This section makes a small number of key assumptions about the conditions bearing on the growth of a California biomass-to-ethanol industry over the next decade, and projects a scenario—one of many possible scenarios—that portrays a middle course toward the usage of biomass-based ethanol as a transportation fuel.

The first, and most important, assumption is a unified state policy, Item (3) above, that might include the first two actions in the list, and make the fourth possible.

The second set of assumptions concerns competition. Ethanol from Midwest corn will initially supply California market requirements. Ethanol from California waste biomass and from Midwest corn stover will then win increasing shares of the market from Midwest corn. California waste biomass will eventually earn the predominant market share over Midwest corn stover due to lower transportation costs, and perhaps by adopting more advanced technologies. Brazilian ethanol from sugar cane will be kept out of the competition by continuing the 54 cents/gallon duty on imports of ethanol.

No technological breakthroughs are assumed, although some may occur. Present laboratory and pilot scale processes are brought successfully to commercial-scale operation. Improved enzymes are produced at lower cost. More efficient feedstock collection and sorting (e.g. collocation of biomass-to-ethanol facilities with MRFs) develops as a common industry practice.

National and state policy support ethanol as an additive to gasoline during the decade from 2000 to 2010. After 2010, these policies remain the same or perhaps become supportive of E85 and neat ethanol as transportation fuels, if the costs of their production are sufficiently reduced.

For example, if MTBE is replaced with 5.7% ethanol in summertime RFG, and with 5.7% or 10% ethanol in winter RFG, the estimated market for ethanol in California is 741 to 909 million gallons annually. But if ethanol replaces MTBE only in premium RFG, and is used in regular gasoline as a 0-3% octane booster year round, the estimated market is 148 to 578 million gallons of ethanol annually. (Ref. VI.5) Perhaps an intermediate figure of 300 to 500 million gallons annually is most likely. In any event, the California

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waste-based biomass-to-ethanol industry will have to compete with the Midwest corn-based biomass-to-ethanol industry for this market.

The technological, economic, and institutional factors discussed in this report are important in determining the market percentages of these competing sources during the years 2000 through 2010. They thereby influence the number and the capacity of California plants that can compete profitably. A 65% share of a 300 to 500 million gallon ethanol market (195 to 325 million gallons annually) in the middle of the decade would support about 10 to 15 plants of 20 million gallons capacity in California using urban, agricultural, and forest wastes to produce ethanol, electricity, and co-products.

Timing is always difficult to predict, but an S-shaped curve is the usual pattern for a growing industry. A projection of sales of ethanol produced from California waste biomass under the preceding scenario might take the following form: 100 million gallons in 2003, 400 million gallons in 2005, 800 million gallons in 2007, approaching 1 billion gallons in 2010.

The 1 billion gallon level could be less or more depending on the policies that are enforced and the technologies that are implemented between now and 2010

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CHAPTER VII

ECONOMIC EVALUATION

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VII. Economic Evaluation

Introduction

This Chapter evaluates the economics of biomass-to-ethanol production in California compared with obtaining ethanol from conventional sources. The following topics are covered:

- Approach to assessing economic analysis of ethanol from biomass,
- Cost to produce ethanol at conventional facilities
- Near- and intermediate-term costs to produce ethanol in California,
- Assumptions for the cost of feedstocks to California biomass
- Assumptions in economic analysis
- Modeling results for California biomass ethanol production costs
- Long-term California ethanol production costs

Approach to Assessing Economic Analysis

This analysis includes a number of different production scenarios which incorporate different feedstock and process options along with other implications such as employment.

Ethanol production costs were estimated for corn dry milling and wet milling process for the near-term, mid-term and long-term timeframes (2002, 2007 and 2012). Production costs were then estimated for four types of California biomass, using two technologies in the three timeframes. Finally the economics of ethanol-only facilities are compared to biorefineries.

Conventional Ethanol Production Facilities

The costs of ethanol produced in corn-based plants were estimated to form a benchmark. The newest of these plants use the latest wet milling processes integrated with electric power generation and food and animal feed products. Resulting ethanol prices are affected by feedstock prices, (plant size, operating costs, interest rates, etc.) the markets for co-products, and other factors.

ProForma Systems modeled both dry milling and wet milling processes to provide a comparison with fuel ethanol produced in California from cellulose-based feedstocks. Ethanol production costs for corn dry milling and wet milling were determined with ProForma Systems' proprietary Virtual Process Simulator that allows rapid and detailed analysis of chemical and biological processes. Each model is based on detailed process flow diagrams for the respective ethanol production technology.

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Several factors affect the economics of ethanol production from corn using dry or wet milling processes. These include corn prices, value of the co-products, and the size of the ethanol facility. Many states also have ethanol production or use incentives that improve the economics for many smaller ethanol facilities.

To estimate ethanol production costs in the near-term, corn price is assumed to be \$2.50 per bushel and the distillers' dried grains value is assumed to be \$85 per ton. For a 20 million gallon per year dry mill, the resulting production cost is \$1.23 per gallon. For a 200 million gallon per year wet mill, the near-term ethanol production cost is estimated to be \$0.97 per gallon (with the value of wet mill co-products gluten meal, gluten feed and germ at \$240, \$65, and \$250 per ton, respectively).

Figure VII-1 shows the sensitivity of ethanol production costs, both dry and wet milling, to corn prices. For dry milling at 20 million gallon per year plant size, ethanol costs range from \$1.09 to \$1.71 per gallon for corn prices from \$2.00 to \$4.00 per bushel. For wet milling at 200 million gallon per year plant size, ethanol costs range from \$0.88 to \$1.50 per gallon for corn prices from \$2.00 to \$4.00 per bushel.

Figure VII-2 shows the sensitivity of ethanol production costs to plant size. Dry mill ethanol production capacities are typically in the range of 10 to 30 million gallons per year with two existing dry mill facilities at 65 and 75 million gallons per year. Wet mills are typically much larger, ranging from 50 to 200 million gallons per year with one wet mill facility at 330 million gallons per year.

With corn at \$2.50 per bushel, ethanol production costs range from \$1.35 to \$1.07 for dry mill plant sizes from 10 to 75 million gallons per year. For wet mills, ethanol production costs range from \$1.14 to \$0.97 per gallon for plant sizes from 20 to 200 million gallons per year.

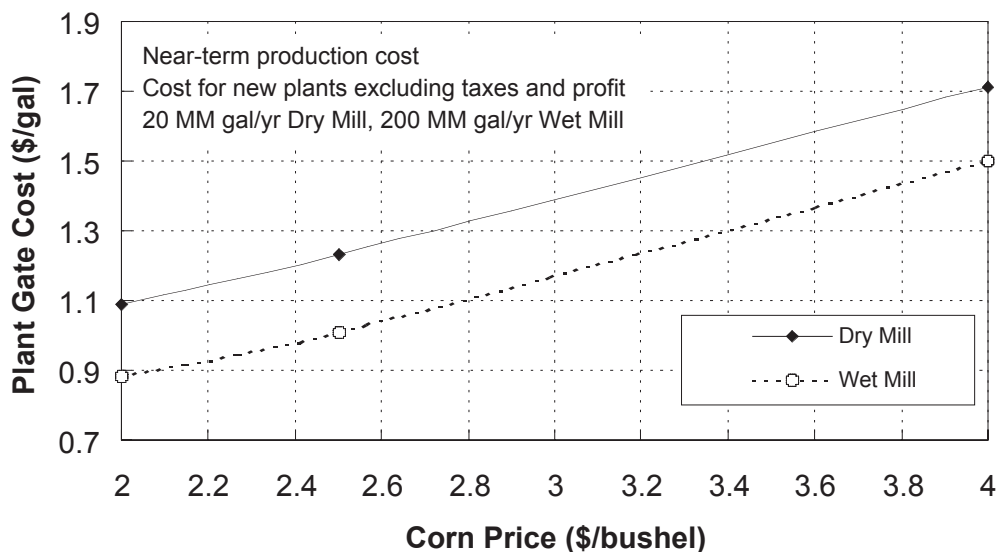


Figure VII-1. Ethanol cost sensitivity to corn price
Source: Evaluation of Ethanol Production Costs, Appendix G

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Dry and wet milling ethanol production costs are assumed to decrease in the mid- and long-term scenarios. Improvements will likely be in the areas of increased ethanol yields per bushel of corn, the development of higher value co-products, and reduced operating costs. Dry milling ethanol production costs are estimated to be \$0.98 to \$1.26 per gallon in the long-term. Wet milling ethanol production costs are estimated to be \$0.91 to \$1.04 per gallon in the long-term.

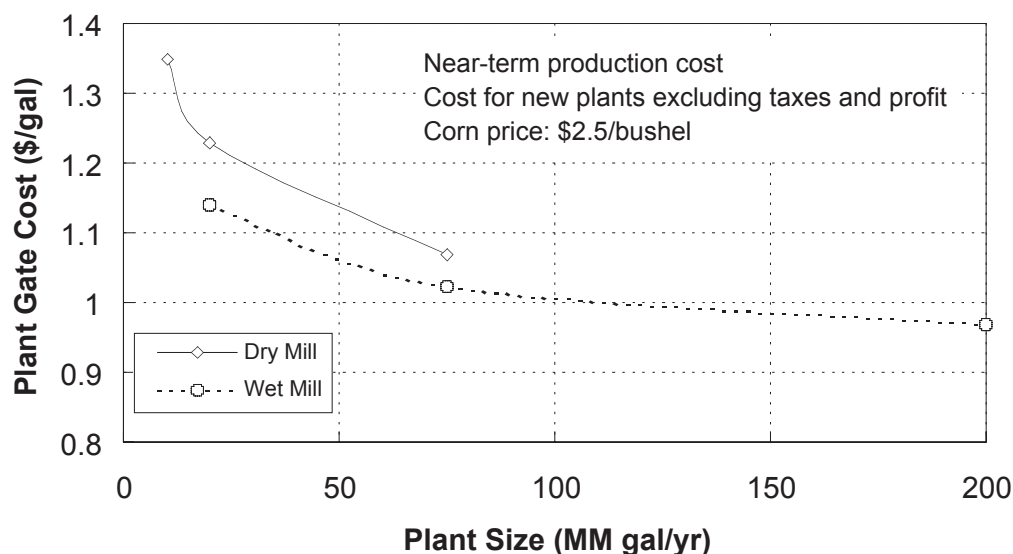


Figure VII-2. Ethanol cost sensitivity to plant size
Source: Evaluation of Ethanol Production Costs, Appendix G

Short and Intermediate Term California Ethanol Production Costs

As discussed in Appendix D, several cellulose conversion options have been analyzed for feedstocks in California. These analyses have shown similar production costs among several near-term technologies to convert biomass to ethanol, with the same level of technology maturity.

The National Renewable Energy Laboratory has undertaken extensive evaluations of ethanol production (Sheehan). Figure VII-3 shows a comparison of production cost estimates for the leading technologies. These estimates indicate that the cost to produce ethanol, for a fixed set of assumptions, overlaps considerably between the different technologies. These costs depend on several factors, including site-specific details, feedstock composition, and enzyme costs. Ethanol production costs are comparable for two-stage dilute acid, concentrated acid, and enzyme processes. Gasification results in an improved product yield and projected lower cost; however, the technology is developmental.

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The success of a future commercial biomass-to-ethanol industry is likely to depend more on feedstock costs and improvements in process technologies that apply to several technologies, rather than which technologies are used. For the purposes of these evaluations, the two-stage dilute acid and enzyme processes were used to estimate production costs. The two-stage dilute acid process is the closest to commercial technology and has been selected for several projects. At this point, it is difficult to project which technologies will be the most economic in the long term because technological improvements in the biological processes will increase the ethanol production and reduce enzyme costs. The enzyme process can achieve improved overall economics compared to the two stage dilute acid process if ethanol yields are increased and enzyme costs are reduced.

Gasification/fermentation has the potential for the highest yields and lower estimated production costs as the lignin fraction of the biomass can also be converted to ethanol. This technology is experimental and the outlook for commercialization cannot be accurately assessed at this time. In other processes, lignin may be converted to an aromatic oxygenate for transportation fuel.

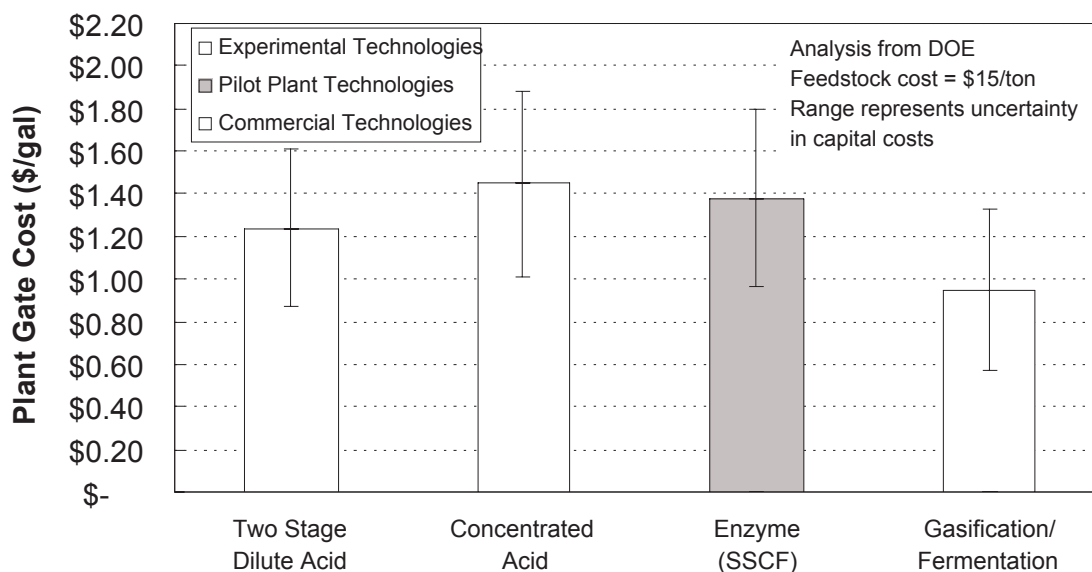


Figure VII-3. Comparison of Ethanol Production Cost Estimates. Source: DOE (Sheehan)

The economics of ethanol production in California were estimated for the plant types shown in Table VII-1. The analysis included scenarios involving different feedstocks, locations, plant types (including grass roots and co-located plants), plant operating assumptions, time frames, and other factors. The following categories of feedstocks were considered:

- Forest thinnings and timber harvest residues,
- Agricultural residues,
- Urban waste, and

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- Eucalyptus trees as an example of energy crops

These categories represent large potential sources of biomass in California.

Table VII-1. Biomass plant configurations for modeling and economic evaluation.

Technology	Plant Type
2-stage dilute acid	grass roots
2-stage dilute acid	co-located
Acid/enzyme (SSF)	grass roots
Acid/enzyme (SSF)	co-located

The analysis covered three timeframes—near-, mid- and long-term (2002, 2007 and 2012). The two-stage dilute acid and the acid/enzyme technologies as well as other biomass-to-ethanol conversion technology options are discussed in detail in Chapter V.

As discussed in Appendix D, biomass-to-ethanol conversion technologies are in their infancy and significant improvements in ethanol production costs are expected as the technologies mature. Over the long-term, ethanol production in California would evolve towards improvements in processing technology. As experience is gained in biomass-based production, the net costs to produce ethanol are expected to be reduced because of increased ethanol yields, reduced enzyme costs, and additional value-added co-products.

Because there are no commercial biomass ethanol plants in operation, numerous assumptions are required to estimate biomass ethanol production costs. Several variables affect the cost to produce ethanol, including the feedstock price and composition, plant size, ethanol and co-product yields, co-product credits (revenues), capital and operating costs, and project financing. The following provides more detail on the assumptions for the two-stage dilute acid technology and acid/enzyme technology analysis in the near-, mid- and long-term (Appendix G presents more detail on the economic analysis.)

Feedstock cost assumptions for California biomass ethanol

The cost and quality of feedstocks are key parameters that affect the cost of ethanol production. The outlook for feedstock costs for forest materials, agricultural materials, urban waste, and energy crops was considered for near-, mid- and long-term time horizons. Feedstock prices are likely to be affected by the size of ethanol plant as transportation costs increase as material must be transported for a larger distance to the plant. It is likely that most ethanol plants would operate on a mixture of feedstocks to adjust for seasonal availability and take advantage of the lowest price materials.

Some feedstocks (forest thinnings, rice straw, segregated waste paper) can potentially receive subsidies that reflect economic and environmental benefits that would not be realized if these materials were not reused or transformed to ethanol. The effect of eliminating subsidies in the mid- and long-term were considered. Detailed assumptions on feedstock costs are presented in Appendix G.

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Lumbermill waste and forest thinnings were considered for plants operating on forest material. Removing biomass from forests that have a high risk of fire costs about \$30/ton. The benefits of harvesting forest thinnings also includes increasing water available for larger trees, reduced fire fighting costs, and potentially reducing insect damage. For ethanol plants collocated with a biomass power plant, it was assumed that lumbermill waste could be purchased and lignin sold to the plant at the same price of \$20/ton. Electric power could be purchased from a collocated plant for \$0.05/kWh while a higher purchase price of \$0.08 that includes distribution costs was assumed for grass roots plants. The amount of lumber mill waste is limited for any ethanol plant. Larger ethanol plants were assumed to use additional forest thinnings as the feedstock for additional capacity.

A combination of rice straw, orchard prunings, other agricultural waste, and urban tree trimming material was assumed as a feedstock for plants operating on agricultural residues. Materials such as orchard prunings are expected to be relatively expensive as these are also feedstocks for biomass power plants. Other woody agricultural materials as well as suburban tree prunings were considered as feedstocks.

Rice straw cannot be burned in power plants, as its silica content is too high. For an ethanol plant operating on a rice straw mixture, disposing of the lignin and solids poses a problem as the remaining solids would contain high levels of silica that would erode power plant boilers if burned. Consequently, the plant is expected to operate part of the year on rice straw and the lignin would be disposed of as a soil amendment for a transportation cost of \$10/ton. Arkenol has developed a process for separating the silica from rice straw and refining it as a high value co-product for their concentrated acid process. While the economics of this process were not evaluated, it provides another approach for using rice straw as an ethanol feedstock.

Currently, a tax credit of \$15/ton is available for a limited quantity of rice straw in California. The tax credit is intended to help defer the cost of not burning rice straw in fields. The economic effect of different amounts of rice straw in the feedstock mix were analyzed with less rice straw used in the feed mix if the tax credit were not available.

Plants using urban waste feedstocks were assumed to operate on a mixture of urban wood waste, tree trimmings, newspaper, and separated waste paper. An urban waste-based facility could be located at a MSW processing facility. This siting would minimize transportation costs and provide access to a wide array of feedstocks. For smaller 30 million gallon per year ethanol facilities located at MSW facilities, transportation costs were assumed to be zero for waste materials. A combined MSW processing and ethanol facility would not likely be located with an existing biomass power plant; therefore, feedstock transport costs were assumed to increase for facilities located at biomass power plants. Waste paper may also be available from material recovery facilities which serve as separation and transfer stations for urban waste. Locating the ethanol plant at such a facility would reduce transport costs and disposal costs.

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Many waste streams such as office waste contain a high portion of waste paper. The paper that is not recycled is more likely to be contaminated with food waste, grease, liquids, and other materials, but still useable for ethanol production. There are not many competing uses for contaminated paper. Such facilities may handle up to 360 tons of paper per year. This quantity is sufficient for a small ethanol plant. Supplemental feedstocks such as yard waste and tree chips, as well as urban wood waste, if available, would provide sufficient material for a 30 MM gal/year plant.

An ethanol plant located with a material recovery facility may be able to obtain waste paper feedstocks in the range of 0 to \$10 per ton after clean-up costs are taken into account. The target price for such a facility is \$1.10 to \$1.19/gal. This price is less than that of a facility located at a power plant where the feedstock must be transported and market prices must be paid for the material. Larger ethanol plants will likely need to transport feedstocks from other material recovery facilities.

Wood waste, tree trimmings, and yard waste are separated in many areas and would be suitable feedstocks for ethanol production. Competing uses for the highest quality of urban wood waste would require blending with lower value feedstocks such as tree prunings to reduce feedstock costs. Most urban wood waste that is currently burned in biomass power plants consists of larger branches from tree pruning and removal, with very little clean wood residue from furniture and lumber operations. Urban wood waste is a limited resource for existing biomass power plants and, if used as an ethanol feedstock, the price and transportation distance would increase. If lignin from ethanol production proves to be a suitable fuel for biomass power plants, the lignin could replace some or all of the feedstock for power plants and eliminate the potential competition for a limited resource.

Chipped tree branches and yard waste are another potential feedstock. These materials are either composted or used for landfill cover and are not suitable as fuels for biomass power plants. Sorting and quality control steps may need to be taken with branches and yard waste, as these can quickly rot, may contain unexpected contaminants, and can have a high ash content. Waste paper provides another potential feedstock. Newspaper is currently recycled, has a relatively high value, and would not be economic for ethanol production.

Waste paper separated from municipal waste solids is a potentially large source of biomass. However, separating the waste paper would likely require some form of hand sorting and would, thus, be costly. The current "tipping fee" costs at landfills are about \$20/ton which would reduce the cost of waste paper (landfills charge a fee, known as a tipping fee, for trucks to dump wastes).

A net feedstock cost would be \$10/ton, or the cost of separated paper less the subsidy and current value of the tipping fee.

Currently, facilities using urban wastes to produce ethanol are not planned in California, so such plants were analyzed for the mid- and long-term. Segregated waste paper was

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only assumed to be available as a feedstock in the mid-term if a subsidy was available; however, it was considered a candidate feedstock for the long-term without a direct subsidy.

Energy crops could provide additional feedstocks for ethanol production. Eucalyptus was assumed as a potential energy crop, since it has low water requirements and could be grown in many parts of California. It also could be used in areas where groundwater contamination may be mitigated by planting trees. Near- or mid-term energy crop scenarios were not considered, as several years are required to establish an initial harvest.

Economic analysis assumptions

Table VII-2 shows the key assumptions for the economic analysis. Mixes of feedstocks were evaluated for each category of biomass. In the near- and mid-term, subsidies for the feedstocks with environmental benefits were assumed to be available. Subsidized feedstocks comprised 50 to 81 percent of the mix of biomass for ethanol plants in the 40 to 50 million gallon per year capacity.

In the analysis, many factors were assumed to vary with the timeframe such as the ethanol production yields, enzyme costs, and risk associated with building an ethanol plant. Mid-term feedstock costs are summarized in Table VII-3.

The process assumptions for the near-term scenarios are based on research by the National Renewable Energy Laboratory, including processes such as hydrolysis sugar yields, fermentation ethanol yield, and the two-stage technology. These near-term values have been demonstrated by bench- and pilot-scale tests at the National Renewable Energy Laboratory.

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Table VII-2. Summary of key assumptions for economic analysis

Category	Feedstocks	Feedstock Subsidy (\$/ton)			
		Near	Mid	Mid	Long
<u>Subsidy Assumptions</u>		Yes	Yes	No	No
Forest Material	Forest thinnings	30	30	0	0
	Lumbermill waste	0	0	0	
Agricultural Residue	Rice Straw	15	15	0	0
	Agr. Waste, wood waste	0	0	0	0
Urban Waste	Separated waste paper	NA	0	0	0
	Wood waste, others	NA	0	0	0
Energy Crops	Eucalyptus	NA	NA	NA	0
<u>Economic Assumptions</u>					
Equity Ownership (%)		25	25	25	25
Interest rate on Debt (%)		8	8	8	8
Hurdle rate (%)		30	25	25	20

NA = not applicable. Feedstock was not evaluated in this timeframe

Source: *Evaluation of Feedstock Costs, Appendix G*

Table VII-3. Summary of feedstock cost assumptions

Feedstock Category	Composite Cost (\$/ton)		Feedstock Materials	Cost (\$/ton)
	Yes	No		
Subsidy Assumption	Yes	No		
Forest Material	14.7	39.0	Forest thinnings	43.5
			Lumbermill waste	20.0
Agricultural Residue	18.4	25.9	Other Ag. Waste	13.4
			Rice Straw	27.9
			Orchard prunings	31.0
Urban Waste	—	22.4 (16)	Separated waste paper	35.7 (10)
			Yard waste	10.2
			Urban wood waste	18.6
			Tree pruning chips	13.1
Energy Crops	—	43.6	Eucalyptus	43.6

Feedstock costs for mid-term 40 to 50 MM gal/year ethanol capacity. Transportation costs vary with plant size. Larger plant sizes require more feedstock and greater transportation distances. Small urban waste plants can obtain low cost waste paper feedstocks if located with a material recovery facility.

Source: *Evaluation of Feedstock Costs, Appendix G*

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The mid- and long-term values are hypothetical, based on engineering judgments. The mid-term case includes using the limits of theoretical yields for two-stage dilute acid technology using hydrolysis reactors. The long-term case includes using improved technology such as counter-current or enzymatic hydrolysis. Some of these technologies are also being implemented in the paper and textile industries.

The required sales price of ethanol at the plant gate was calculated for a fixed hurdle rate that was reduced over time. (This price is referred to as the target price in subsequent discussions; the actual price will depend upon market conditions.) In the short-term, a higher hurdle rate was assumed to be necessary to attract investors to a riskier technology. As the technology matured and risks diminished, the required hurdle rate was assumed to decline.

Co-products generated in this process can significantly lower the net production cost of ethanol. For the near-term case lignin to be used as boiler fuel is the only co-product assumed to be sold. In the mid- and long-term cases, higher value chemicals are produced from the hydrolysate sugars and/or from the lignin, as well as high value chemical production from biomass extractives.

Two-stage dilute acid technology assumptions

Fermentation of the six-carbon sugars to ethanol in the near-term case is assumed to be accomplished with commercially available yeast such as *Saccharomyces cerevisiae*. (Six-carbon sugars are derived from cellulose while five-carbon sugars are derived from hemicellulose. Only the six-carbon sugars glucose, mannose and galactose are fermented to ethanol.)

For the near-term to long-term plants, ethanol production yields were assumed to increase with improvements in hydrolysis and fermentation. With forest material, the result were an increase from 84 to 101 gallons per ton for the two-stage dilute acid process from near-term to long-term plants. The yield depends on the amount of fermentable sugars in the feedstocks. The lowest yields are associated with rice straw and the highest yields are associated with clean paper.

Prior studies by the National Renewable Energy Laboratory considered single-stage dilute acid processes with a near-term yield of 52 gallons per ton in the near-term. Early two-stage processes had only slightly higher yields. However, current pilot plant data supports the estimate of 84 gallons per ton for forest materials.

The ethanol yields in this case are equal to those obtained in the laboratory by NREL for two-stage dilute acid hydrolysate¹. The ethanol fermentation yields for the mid- and long-term cases assume the use of a genetically engineered yeast or bacteria which

¹ Same references

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utilizes xylose in the mid-term, and all of the sugars in the long-term. Increasing fermentation temperatures are also assumed as new technology is developed. Higher fermentation temperatures will reduce the process energy use and increase the rate of fermentation.

Acid/enzyme technology assumptions

The National Renewable Energy Laboratory has conducted bench- and pilot-scale tests to determine many of the near-term process values. The mid- and long-term values are hypothetical, based on engineering judgment, with the goal of reducing the overall cost of ethanol production. For enzymatic conversion plants, the yield is expected to improve from 97 to 105 gallons per ton from the mid-term to long-term time horizon with forest material feedstocks.

Acid/enzyme technology modeling assumptions for the near-term scenarios are based in large part on research conducted by the National Renewable Energy Laboratory. A simultaneous saccharification and co-fermentation (SSCF) process has been modeled, as opposed to other enzymatic technology options such as separate hydrolysis and fermentation. Key ethanol production parameters include pretreatment effectiveness (hemicellulose sugar yields and reactivity of the remaining solids to enzymatic hydrolysis), cellulase enzyme productivity and activity and SSCF sugar and ethanol yields. Many of the near-term process values have been demonstrated by bench- and pilot-scale tests at NREL. Mid- and long-term values are hypothetical values based on engineering judgement and NREL's goals for reducing overall ethanol production costs.

Collocated ethanol facility assumptions

Collocating biomass ethanol facilities with existing biomass power plants can result in several interfaces that can have significant economic benefit to each facility. These interfaces can reduce capital cost of the ethanol facility, decrease fixed and variable operating costs for both facilities, create new revenue streams for existing biomass power plants, and make both facilities more competitive in their respective markets. The interfaces and corresponding economic benefits of co-locating ethanol facilities with existing biomass power plants will likely vary somewhat from site to site.

A collocated facility has several economic advantages. The cost of processing feedstocks is shared for both facilities. The ethanol facility can contract with the biomass power plant to manage feedstock procurement and inventory, which reduces the fixed operating costs for both facilities. The ethanol plant can also process feedstocks that would be burned in the biomass power plant and provide lignin as a fuel for the power plant. For a stand-alone facility, lignin could be burned in a boiler to generate steam, but excess lignin would need to be transported to a biomass power plant, which would reduce the potential income from the lignin. Handling and transaction costs for lignin are minimized with a co-located facility.

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Modeling results for California biomass ethanol production costs

Ethanol production costs presented below were determined with ProForma Systems' proprietary Virtual Process Simulator. Each model is based on detailed process flow diagrams for the respective ethanol production technology. Stand-alone and co-located biomass ethanol facilities are also analyzed with the simulator.

Table VII-4 shows the cost estimates for mid-term production scenarios using the two-stage dilute acid process. The values correspond to the median plant sizes. In the mid-term, cost estimates are lowest for the co-located facilities using the two-stage dilute acid process. Costs for the acid/enzyme process are notably higher. Long-term costs are much lower as enzyme costs are expected to be reduced substantially.

Table VII-4. Mid-term ethanol production cost estimates^a.

Technology		2-Stage Dilute Acid		Acid/Enzyme
Subsidy		Yes	No	Yes
Feedstock	Plant Type	Ethanol Production Cost (\$/gal)		
Forest	Stand alone	1.18	1.46	1.55
Material	Co-located	0.88	1.16	1.17
Agricultural	Stand alone	1.37	1.44	1.76
Residue	Co-located	1.03	1.08	1.33
Urban/Mixed	Stand alone	1.12	1.44 (1.12 ^b)	1.52
Waste	Co-located	0.82	1.12	1.16

^a Midpoint feedstock cost estimates. 40 MM gallon/yr plants for forest and agricultural materials. 50 MM gallon/yr plants for urban waste. Stand-alone urban waste plant is located with a material recycling facility.

^b Feedstocks costs can be lower for ethanol plants integrated with a material recovery facility. For larger plants, waste paper must be obtained from other facilities. Value in () represent low cost waste paper.

Source: Evaluation of Ethanol Production Costs, Appendix G

Several key variables were evaluated to show the sensitivity of ethanol production costs to:

- Ethanol plant size
- Delivered feedstock cost
- Feedstock composition
- Ethanol selling price
- Ethanol facility capital cost

Of the variables evaluated, the cost of the feedstock has a very important effect on the economics of ethanol production. Production economics were analyzed for feedstocks with and without subsidies shown in Table VII-2. Materials that could potentially be subsidized (forest thinnings, rice straw, and waste paper) were estimated to make up 50 to 80 percent of the feedstocks.

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Figure VII-4 shows prices of ethanol that would be economic in the mid-term. (The ethanol target price represents the sales price that would cover capital and operating costs and provide the rates of return indicated in Table VII-2. This price value can be compared directly with the projected price of ethanol from out-of-state sources discussed in the following subsection to assess if in-state ethanol production can be economic.) Existing subsidies and tax credits on forest thinnings and rice straw, as well as potential subsidies or increased tipping fees for waste paper, significantly improve the economics of mid-term ethanol production. Increasing plant size also reduces production costs, but the feedstock cost is the key consideration.

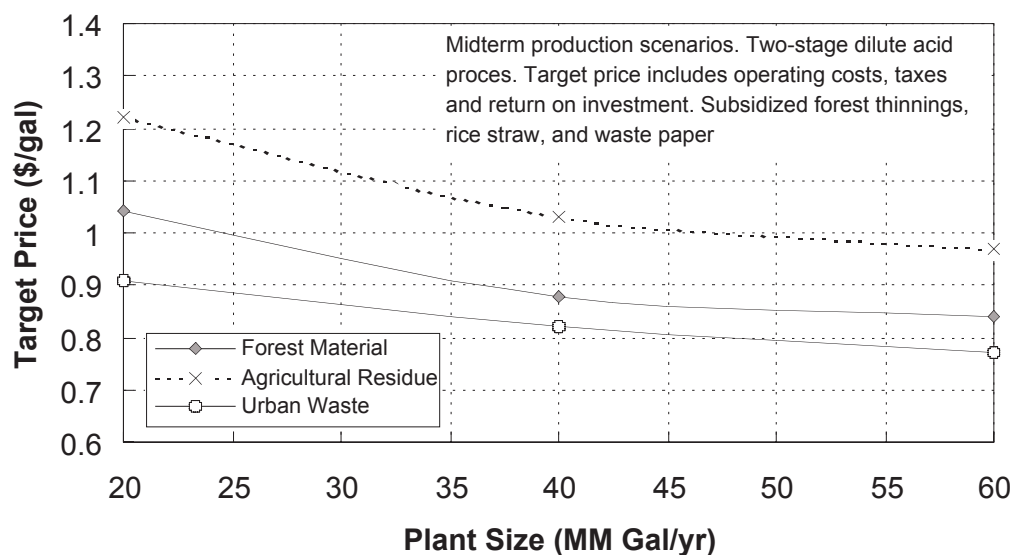


Figure VII-4. Effect of Plant size on economic ethanol price. Ethanol plants located with biomass power plants *Source: Appendix G*

If rice straw or waste paper were not subsidized, it was assumed that more tree waste and urban wood waste would need to be used as feedstocks for agricultural and urban-based plants. The availability of such materials is currently limited, which would be an obstacle for the economic production of ethanol.

Transportation costs also affect feedstock costs; the effects of transportation distance and related costs were included in the cost assumptions.

Transportation costs will likely limit agricultural and forest material plants more than other types of facilities, since forest roads and dispersed agricultural resources result in greater transportation distances. Transportation costs also increase with urban waste; however, the need to dispose of waste materials combined with the long distances already traveled for waste disposal could make urban waste materials available for larger plants.

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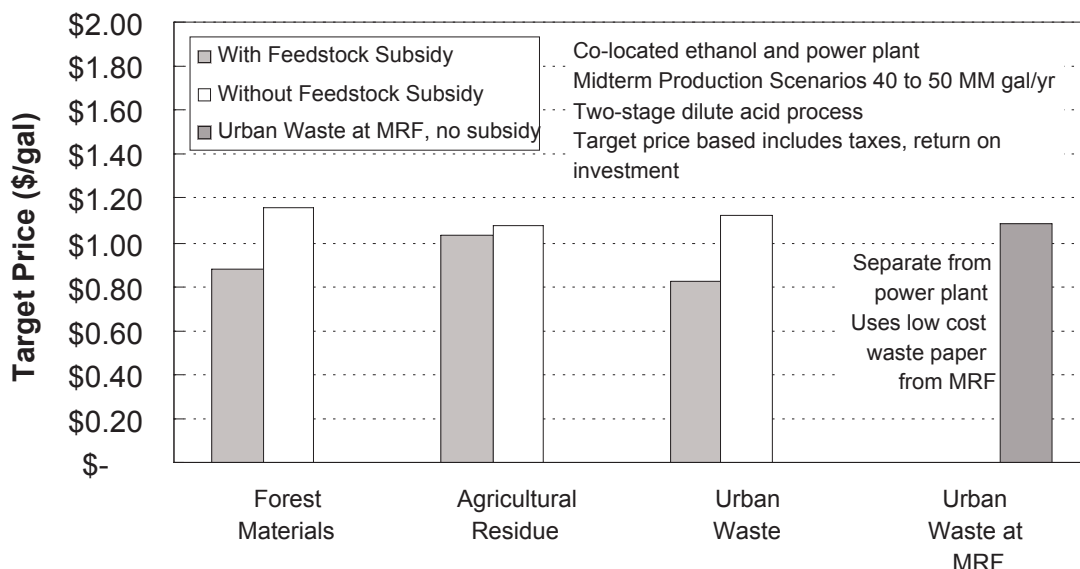


Figure VII-5. Effect of feedstock cost and subsidy. Source: Appendix G

Long-Term California Ethanol Production Costs

Over the long term, ethanol production in California would evolve towards improvements in processing technology and additional feedstock resources. As experience is gained with cellulose-based production, the net costs to produce ethanol are expected to be reduced because of increased ethanol yields, reduced enzyme costs, and the opportunity for additional value added co-products. Additional feedstocks such as energy crops and additional urban waste materials may be economic. The cost of long-term ethanol production takes into account improvements in production technology and increased availability of feedstocks.

Figure VII-6 illustrates the effect of projected improvements in production yield and enzyme costs as ethanol production technology advances. The mid-term improvements in yield are very likely to occur, as the same technology improvements are also underway in the paper and textile industries and are being applied to ethanol production with pilot plant developments. Very large plant sizes on the order of 200 million gallons per year for urban waste will also improve the economics of ethanol production

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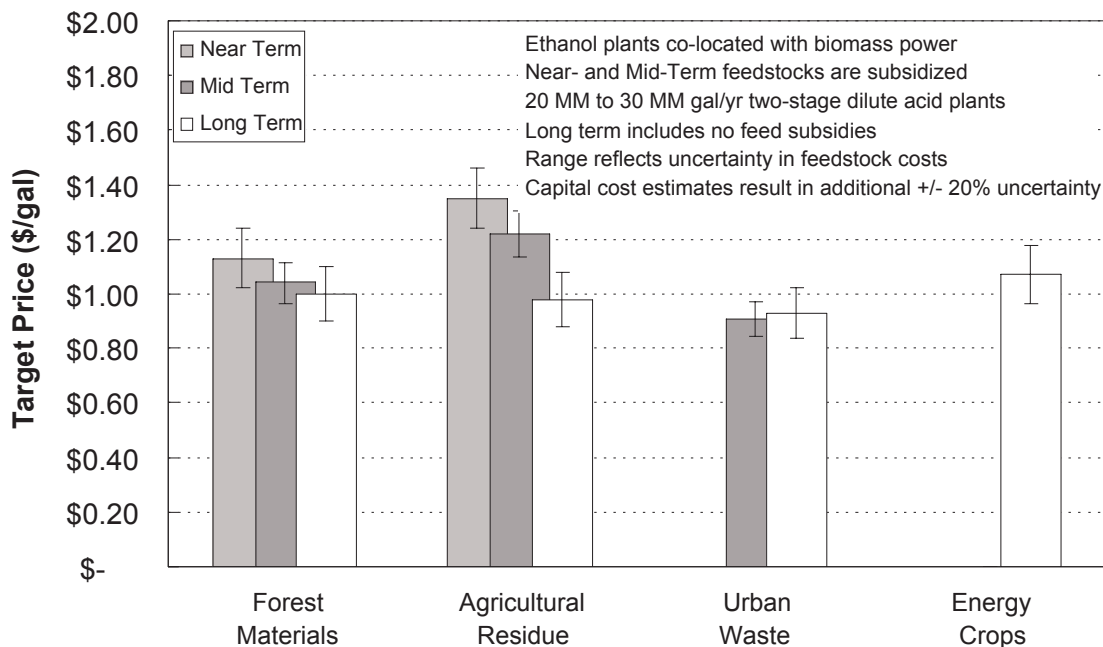


Figure VII-6. Economic ethanol prices decrease with advances in technology.
Source: Evaluation of Ethanol Production Costs, Appendix G.

Ethanol Supply/Cost Outlook from Out-of-State Sources

Ethanol sources from out-of-state were examined in terms of the expected cost to produce ethanol. Also examined was the potential for these sources to meet the demand for increased or sustained ethanol in California in the longer term.

Ethanol from out-of-state sources was examined in terms of the expected price of ethanol. Also examined was the potential for these sources to meet the demand for increased or sustained ethanol markets in California in the longer term.

The delivered price of out-of-state ethanol was determined by estimating its competing value as a gasoline blending component. Available production capacity, state-by-state pricing of gasoline, transportation costs, and state tax credits determined the delivered price to California. A baseline gasoline wholesale price of \$0.62/gallon and MTBE price of \$0.85/gallon are assumed.

Figure VII-7 illustrates the intermediate-term supply curve for ethanol delivered to California. The available supply corresponds to the price at which ethanol supplies in the Midwest and other states can be bid away from gasoline blenders in those regions. The breakeven price at which each state values ethanol was then matched with the corresponding volume of ethanol used by each state. Unused U.S. capacity as well as ethanol imported through the Caribbean was considered in the supply curve.

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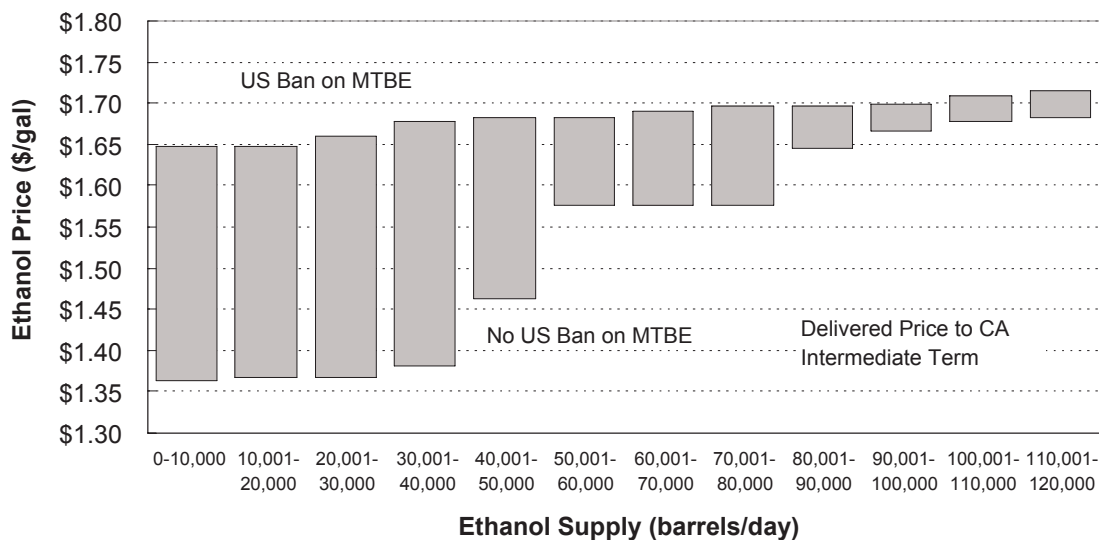


Figure VII-7. Near term ethanol supply costs. *Source: Appendix G*

The result is illustrated in Figure VII-7. For the first 10,000 bbl.day delivered to California, the price would range from \$1.36 to \$1.65/gallon depending upon whether the use of MTBE is banned in states other than California. If MTBE is banned throughout the U.S., the resulting intermediate term cost curves for ethanol delivered to California will be correspondingly higher. Assuming the oxygenate mandate remains in place, blenders outside California would compete with California blenders for the existing ethanol supply. All ethanol in the U.S. would be valued as an oxygenate instead of as a lower value blending component for gasohol. For larger volumes of ethanol up to 120,000 bbl/day, the price increases to about \$1.70/gallon. These prices would decrease with a decrease in the price of gasoline.

This intermediate-term cost curve assumes that blenders outside California have access to the alternative oxygenates. If they must use ethanol as well, then there will be a substantial imbalance between demand and supply for ethanol. The resulting bidding war for the limited supply of ethanol cannot be determined from fundamental valuations alone, but the price spikes could be substantial.

Longer-term ethanol prices, shown in Figure VII-8, can be expected to moderate to the marginal cost of production. However, this ethanol production cost will increase as more corn is used to produce ethanol (increasing the price of corn) and as the by-products (such as distiller dried grains, gluten meal and gluten feed) drop in value due to their increased supply. A notional production cost was estimated using various assumptions regarding baseline corn costs and by-product costs. Corn elasticity values were corrected in this report relative to the previous CEC report, which increased the rate at which corn prices increase with added ethanol usage.

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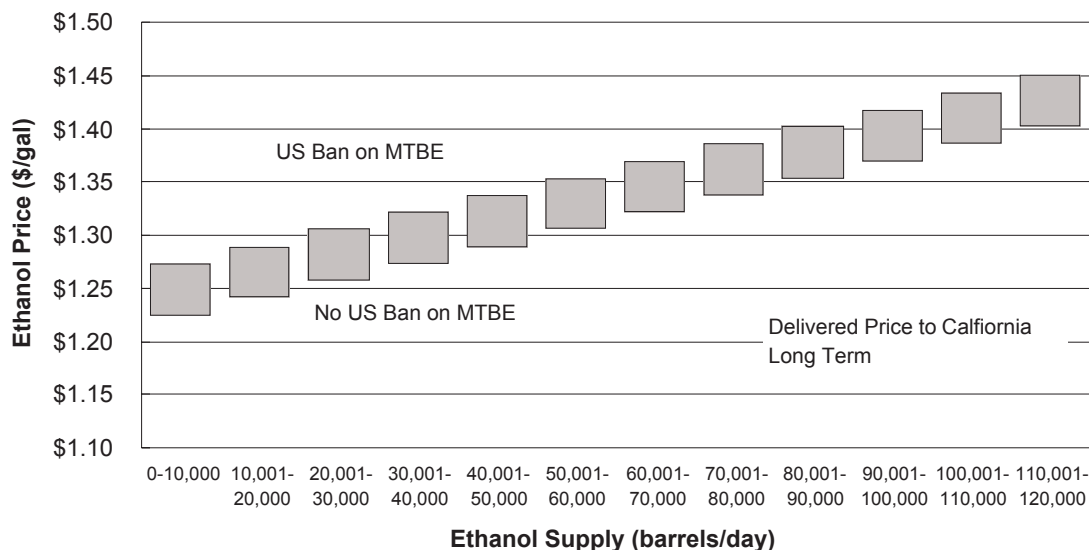


Figure VII-8. Long term ethanol supply costs. Source: Appendix G

The result is a supply curve which delivers ethanol to California at \$1.24 to \$1.27/gallon for the first 10,000 barrels per day. The price of ethanol delivered to California under a U.S. MTBE ban represents the upper range of the curve. Increasing the supply raises the price by \$0.20/gallon.

Ethanol from other sources has limited potential as a fuel. Synthetic ethanol, derived from the petrochemical industry does not qualify for the \$0.54/gallon federal tax credit so new supplies for vehicle fuel would not be likely. In Brazil, gasoline is required to contain 20 percent ethanol, so supplies are also limited. Trade agreements limit Caribbean ethanol to 10 percent of U.S. production. Therefore, corn-based ethanol is the most significant source of ethanol for fuel uses.

Economic Opportunity and Risk Factors Associated with a California Ethanol Industry

The economic benefits associated with development of a California biomass-to-ethanol industry include:

- Support continued rice farming in the Sacramento Valley by providing a practical straw disposal alternative to burning.
- Help dispose of other agriculture wastes such as orchard prunings and agriculture crop residues.
- Reduce wild fire costs and losses by using forest wastes as a feedstock, decreasing the volumes of wildfire fuels.
- Divert municipal solid waste from landfills
- Improve air quality and thus reduce medical costs associated with air pollution.

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- f) Reduce ethanol imports to the state if ethanol is found to be an acceptable alternative to MTBE.
- g) Create jobs, new tax base and economic development in California.
- h) Create new biomass power revenues by co-locating ethanol plants with existing biomass power plants. This improves the economics of biomass power production, enabling biomass power to better compete in California's new deregulated electricity markets.
- i) Reduces California's dependence on imported MTBE and related balance of payment.

Risks associated with development of a California biomass-to-ethanol industry include:

- a) The pace of biomass technology development will impact biomass ethanol production costs. A slower pace will result in higher ethanol production costs which could adversely affect the California biomass ethanol industry. A faster technology development pace would be beneficial to the establishment of a biomass ethanol industry in California
- b) Biomass feedstock prices have a significant impact on the ethanol production costs estimated here. Higher feedstock prices could make California biomass ethanol less competitive with other sources of ethanol and restrict the size of the California ethanol industry.
- c) Development of assured future ethanol fuel markets in California is seen as a critical factor for justifying investment in an ethanol production industry in the state.
- d) The development of high value co-products is anticipated to have significant impacts on ethanol production costs. There are technical and market risks associated with each co-product that must be evaluated. For example, if the market for a co-product is very small, then that co-product may not have much of an impact on a large California ethanol industry.

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References to Chapter VII

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CHAPTER VIII

STEPS TO FOSTER A BIOMASS-TO- ETHANOL INDUSTRY IN CALIFORNIA

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VIII. Steps to Foster a Biomass-to-Ethanol Industry in California

Introduction

The chapter presents findings and the major issues that are likely to affect a biomass-to-ethanol industry in California, including issues about feedstock supply and ethanol product as well as ethanol demand. Project financing and profitability are explored along with federal and state financial assistance.

This chapter also offers several general recommendations to support a biomass-to-ethanol industry if policy makers decide to support this industry. As part of this effort, a state energy policy may be needed to help foster an ethanol-to-biomass industry in California by removing the barriers that hinder the private sector from investing in this industry.

Chapter VII indicates the importance of yet-to-be-defined markets for co-products from future ethanol production facilities and other integrated facilities as an element of reducing the risk of investment in this potential industry.

Underlying these choices is the assumption that California will have to compete with other states for a share of the ethanol market and markets for co-products. Thus, any actions and support for the ethanol industry in other states will have to be considered. Appendix I contains a comprehensive listing of other states incentives and initiatives.

Findings

This section lists the findings and issues in order of importance, with the least important appearing last. These findings and issues form the basis for discussion of whether a state policy to support a waste biomass-to-ethanol industry should be developed which will be discussed at the September 10, 1999 workshop.

Biomass-to-Ethanol Facilities in California

- Large-scale commercial biomass-to-ethanol facilities do not exist in California. Thus, near-term ethanol supplies to meet MTBE phase-out needs by 2003 will likely come from Midwest corn-based ethanol.
- Several advanced biomass-to-ethanol conversion technologies are nearing the commercial stage. Three planned projects in California could produce up to 46 million gallons of ethanol a year in the 2004 to 2005 time frame.
- Existing small scale waste biomass-to-ethanol facilities in California can produce up to 7.5 million gallons of ethanol a year.

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Feedstock Supply /Ethanol Product

- California's estimated gross annually renewable biomass potential is 51 million bone dry tons (BDT), but not all of it is economically available for biomass-to-ethanol conversion. Large volumes of ethanol may be derivable from energy crops sometime in the future; however, energy crops do not offer the waste disposal benefits associated with waste biomass.
- A lower-bound "safe" estimate of sustainable ethanol supply based on a mix of available biomass feedstocks appears to be about 170 million gallons of ethanol a year.
- Corn-based ethanol from the Midwest will supply virtually all of California's ethanol demand in the near-term.

Ethanol Demand

- Two regulatory requirements, which are yet to be determined, limit the ability to assess the demand for ethanol accurately after 2003. These requirements include fuel specifications for California Phase III gasoline and the uncertain outcome regarding the removal of the oxygen requirement from the Clean Air Act Amendments of 1990.
- Upper and lower bounds of 450 and 750 million gallons a year in 2005 are estimated for the two most likely future ethanol demand scenarios.
- Ethanol cost/supply analyses show that Midwest corn-based ethanol will set California's ethanol cost and that Midwest and California ethanol prices will be driven by gasoline prices. Under a favorable gasoline price scenario and proven biomass-to-ethanol conversion technology, California's biomass ethanol should become cost-competitive with Midwest ethanol in 2005 or later.
- Sugar-based Brazilian ethanol could supply much of California's oxygenate need at a price well below that of any California biomass-derived ethanol. The federal ethanol import tariff will continue to be necessary to allow a California biomass-to-ethanol industry to gain a foothold and compete against ethanol from the Midwest.

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Project Financing and Profitability

- High capital costs associated with the non-commercial status of biomass to ethanol technology make financing these facilities high risk. Though potentially limited in number, ethanol facilities co-located with biomass powerplants or waste disposal facilities will be the projects having the greatest chance to succeed economically in the early years.
- Collocated projects are typically financed over a fifteen-year period. With the continuation of the federal ethanol subsidy uncertain beyond 2007, the private sector is likely to see investing in biomass-to-ethanol facilities as an unacceptable financial risk.
- Future markets for new co-products from biomass-to-ethanol biorefinery facilities are uncertain. The private and public sectors will need to assist in developing these markets, thereby helping to reduce the risk of developing biomass ethanol facilities.

Federal and State Financial Assistance

- The federal 54 cent per gallon tax credit for ethanol which begins to drop in 2004 and expires will need to be continued if California is to develop a waste biomass-to-ethanol industry.
- California must offer a state tax credit or another form of financial assistance should the federal 54 cent per gallon tax credit expire or be rescinded.
- California must commit to a level of state support commensurate with that provided by other states to level the playing field and support a California waste biomass-to-ethanol industry.
- State co-investment in the first two or three projects would greatly reduce the real or perceived investment risk in additional California waste biomass-to-ethanol facilities.
- Targeted RD & D funding will advance the state-of-the-art in biomass-to-ethanol (and co-products) technologies best suited to California's waste biomass resources. This funding will enhance California's ability to compete with Midwest corn-based ethanol.

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TECHNICAL APPENDICES

(Published in separate volume)